WORKING DATA

FOR

IRRIGATION ENGINEERS

BY

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PREFACE

Every branch of engineering has its special problems which necessitate the frequent use of certain fundamental data. This requirement has led to the production of "handbooks" or "pocketbooks" to cover the requirements of the various fields and the following pages are the result of an attempt to do this for irrigation engineers. The object has been to produce a book that would result in the conservation of the time and mental energy of the user, as well as to present material not readily obtainable from other sources. Utility has been the primary aim in the selection of the material and in the arrangement of subjects.

The author fully realizes that he has accomplished the desired object to a limited extent only. The first edition of a work of this nature must obviously be incomplete in numerous respects, but it is hoped that this defect may be remedied, in large part, in future editions if such should become necessary. To accomplish this, constructive criticisms and suggestions for additions and improvements are earnestly invited.

A considerable portion of the material is original. Most of the remainder was taken from the publications and records of the United States Reclamation Service, and the author considers himself very fortunate in having had this prolific source of valuable information at his disposal. A few tables of a general nature were collected from various other sources.

It is hoped that the book in its present form will prove to be of value to irrigation and hydraulic engineers, and the author would repeat his invitation for suggestions for its improvement so that the book may be made of the greatest use to the largest number.

E. A. M.

Washington, D. C.,
December, 1914.

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INTRODUCTION

The major portion of this book consists of tables and diagrams. Tables are given generally where their use does not require interpolating for intermediate values; for example: the earthwork tables on pages 208 to 219, where the arguments of the tables are given as close as the measurements are made in the field, but in most other cases graphic representation has been preferred. Diagrams avoid mental interpolation; they throw vividly upon the mind a picture of how the different factors vary. Logarithmic scales are generally used, and for several reasons: First, they allow covering the greatest range of values in a given amount of space; second, on these scales, most of the curves are straight or nearly so, making the reading of the diagram easier than where the lines are curved, as on natural scales; third, from whatever part of the diagram a value is read, the same degree of accuracy is obtained, which is not the case when natural scales are used. Most hydraulic calculations do not warrant the high degree of refinement generally indicated in tables, which is liable to be misleading, especially to the inexperienced. The diagrams give results that are well within the limit of accuracy of the data, and, at the same time, avoid the implication of an accuracy that does not exist.

It seems desirable, before entering on a detailed explanation of the tables and diagrams, to discuss briefly the various features of irrigation engineering, in order to show more completely the applicability of the matter that follows. To this end, the usual steps in the development of an irrigation project are taken up in the order of their sequence, and data are presented that are of assistance in arriving at the proper conclusions.

In discussing the various features, irrigation by gravity from surface waters is kept principally in mind, as this is by far the most important method, but most of the principles apply to irrigation by pumping as well; the main difference being that the latter method generally presents a much simpler problem in the aggregate.

WORKING DATA FOR IRRIGATION ENGINEERS

CHAPTER I

EXAMINATION AND RECONNOISSANCE

Amount of Land Available.—The amount of land available is generally much greater than the available water supply will cover, but a reconnoissance is always desirable to determine its location, both horizontally and in elevation, relative to the source of supply. From this is determined the probable length of the main supply canal, and it can be roughly judged whether the amount of land to be irrigated will warrant the construction of a main supply canal of the length found. The topographic sheets of the U. S. Geological Survey are exceedingly valuable for this purpose, and if such sheets are available for the territory under investigation, very little examination in the field will usually be necessary. Index maps, showing the topographic sheets available, and for sale at 10 cents each, may be obtained upon application to the U. S. Geological Survey. If such sheets are not available, a reconnoissance with hand level, aneroid barometer, and pocket compass will generally be necessary. For reference in establishing elevations, the "Dictionary of Altitudes" and pamphlets giving the results of spirit-levelling in the various States, published by the U. S. Geological Survey, are very useful. These may be obtained by application to the Director, U. S. Geological Survey, Washington, D. C.

Source of Water Supply and Quantity Available.—The flow of rivers comes from two general sources: rain and melting snow. Either of these is likely to produce sudden and large floods, but those produced by the former are, as a rule, much more sudden and violent, and the rivers in arid regions fed principally by rains often go dry, or almost dry, during the summer months, such as the Arkansas River, in Colorado and Kansas, and the

TABLE 1

Numbers of Water-Supply Papers Containing Results of Stream Measurements

	1899a	1900b	1901	1902	1903	1904	1905	1906	1907–8	1909	1910	1911	1912	1913
North Atlantic coast (St. John River to York River)	35	47,c48	65, 75	82	97	d124 e125 f126	d165 e166 f167	d201 e202 f203	241	261	281	301	321	...
South Atlantic coast and eastern Gulf of Mexico (James River to the Mississippi)	g35,36	48	65, 75	g82,83	g97,98	f126 127	f167 168	f203 204	242	262	282	302	322	...
Ohio River basin	36	48,h49	65, 75	83	98	128	169	205	243	263	283	303	323	353
St. Lawrence River and Great Lakes	36	49	65, 75	i82,83	97	129	170	206	244	264	284	304	324	...
Hudson Bay and upper Mississippi River	36	49	j65 66, 75	j83,85	j98 99,100	j128 130	171	207	245	265	285	305	325	...
Missouri River	k36,37	49,l50	66, 75	84	99	130 m131	172	208	246	266	286	306	326	356
Lower Mississippi River	37	50	j65 66, 75	j83,84	j98,99	j128 131	j169 173	j205 209	247	267	287	307	327	...
Western Gulf of Mexico	37	50	66, 75	84	99	132	174	210	248	268	288	308	328	t358
Colorado River	n37,38	50	66, 75	85	100	133	175 o177	211	249	269	289	309	329	...
Great Basin	38,p39	51	66, 75	85	100	133 q134	176 q177	212 q213	250 q251	270 q271	290 q291	310	330	...
California	38,r39	51	66, 75	85	100	134	177	213	251	271	291	311	331	...
North Pacific coast	38	51	66, 75	85	100	135	s177 178	214	252	272	292	312	332	...

a Rating tables and index to Water-Supply Papers 35–39 contained in Water-Supply Paper 39.
b Rating tables and index to Water-Supply Papers 47–52 and data on precipitation, wells, and irrigation in California and Utah contained in Water-Supply Paper 52.
c Wissahickon and Schuylkill rivers to James River.
d New England rivers only.
e Hudson River to Delaware River, inclusive.
f Susquehanna River to Yadkin River, inclusive.
g James River only.
h Scioto River.
i Lake Ontario and tributaries to St. Lawrence River proper.
j Tributaries of Mississippi from east.
k Gallatin River.
l Loup and Platte rivers near Columbus, Nebr., and all tributaries below junction with Platte.
m Platte and Kansas rivers.
n Green and Gunnison rivers and Grand River above junction with Gunnison.
o Below junction with Gila.
p Mohave River only.
q Great Basin in California, excepting Truckee and Carson drainage basins.
r Kings and Kern Rivers only.
s Rogue, Umpqua, and Siletz rivers only.
t including water resources of the Rio Grande Basin, 1888–1913.

Milk River, in Montana. Rivers fed by melting snows are much more reliable as an irrigation supply, but even these often run very low during the summer months.

On account of this variable and flashy nature of streams in the arid regions, it is of the utmost importance that records be obtained not only of the total flow of the stream, but also of the monthly run-off, especially during the irrigation season. For this purpose, the records of the Hydrographic Branch of the U. S. Geological Survey are of great value. Thorough search for records from private sources should also be made. The Geological Survey records are published in various water-supply papers, a general index of the data available to date being given in the accompanying table.

I. *North Atlantic Coast.*—Includes streams flowing into the Atlantic Ocean from St. John River in Maine, to Rappahannock River, Va., inclusive. Principal streams in this division: St. Croix, Machias, Union, Penobscot, Kennebec, Androscoggin, Saco, Merrimac, Mystic, Blackstone, Connecticut, Hudson, Delaware, Susquehanna, Potomac, and Rappahannock. The streams drain wholly or in part, the States of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Jersey, New Hampshire, New York, Pennsylvania, Rhode Island, Vermont, Virginia, and West Virginia.

II. *South Atlantic Coast and Eastern Gulf of Mexico.*—Includes streams flowing into the Atlantic Ocean and Gulf of Mexico from James River, Va., to Pearl River, Miss., inclusive. Principal streams in this division: James, Roanoke, Cape Fear, Yadkin, Santee, Savannah, Altamaha, Apalachicola, Choctawhatchee, Mobile, and Pearl. The streams drain wholly or in part the following States: Alabama, Florida, Georgia, Mississippi, North Carolina, South Carolina, and Virginia.

III. *Ohio River Basin.*—Includes Ohio River with all its tributaries. Principal streams: Allegheny, Monongahela, Beaver, Muskingum, New (or Kanawha), Scioto, Miami, Kentucky, Wabash, Cumberland, and Tennessee. The streams drain wholly or in part the following States: Alabama, Georgia, Illinois, Indiana, Kentucky, Mississippi, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, and West Virginia.

IV. *St. Lawrence River Basin.*—Includes streams which drain into the Great Lakes and St. Lawrence River. Principal minor basins: Lake Superior, Lake Michigan, Lake Huron, Lake Erie, Lake Ontario, and St. Lawrence River. Principal streams flowing into Lake Superior: St. Louis, Ontonagon, Dead, and Carp Rivers. Streams flowing into Lake Michigan are Escanaba, Menominee, Iron, Peshtigo, Oconto, Fox, St. Joseph, and Grand Rivers. Streams flowing into Lake Huron are Thunder Bay, Au Sable, Rifle, and Flint Rivers. Streams flowing into Lake Erie are Huron, St. Marys, Maumee, Sandusky, Black, and Cuyahoga. Streams flowing into Lake Ontario are Genesee, Oswego, Salmon, and Black Rivers. Streams flowing into the St. Lawrence are Oswegatchie, Raquette, Richelieu (the outlet of Lake Champlain), and St. Francis River, whose principal tributary, Clyde River, reaches it through Lake Memphremagog. The streams of this section drain wholly or in part the following States: Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, Vermont, and Wisconsin.

V. *Hudson Bay and Upper Mississippi River Basins.*—Include all streams which drain into Hudson Bay and the Mississippi above its junction with the Ohio (except the Missouri). The principal streams flowing into Hudson Bay from the United States are St. Mary River, Red River, and Rainy River. The principal tributaries of the upper Mississippi are Crow Wing, Sauk, Crow, Rum, Minnesota, St. Croix, Chippewa, Zumbro, Black, Root, Wisconsin, Wapsipinicon, Rock, Iowa, Des Moines, Illinois, Fox, and Kaskaskia Rivers. The streams drain wholly or in part the following States: Illinois, Indiana, Iowa, Minnesota, Missouri, North Dakota, South Dakota, and Wisconsin.

VI. *Missouri River Basin.*—Includes the Missouri with all its tributaries. The principal streams in this basin are Red Rock, Beaverhead, and Jefferson Rivers, which may be considered a continuous river forming the head of the Missouri; below the mouth of the Jefferson the principal tributaries are Madison, Gallatin, Prickly Pear, Little Prickly Pear, Dearborn, Sun, Marias, Judith, Musselshell, Milk, Yellowstone, Little Muddy, Little Missouri, Cheyenne, Niobrara, and Platte (including North Platte and South Platte Rivers), Kansas, Osage, and Gasconade Rivers. These streams drain wholly or in part the following States: Colorado, Iowa, Kansas, Minnesota, Missouri, Montana, Nebraska, North Dakota, South Dakota, and Wyoming.

VII. *Lower Mississippi River Basin.*—Includes all streams flowing into the Mississippi below the mouth of the Ohio. The principal streams in this division are Meramec, White, Arkansas (whose chief tributaries are Huerfano, Purgatory, Cimarron, Verdigris, Neosho, Canadian, and Mora Rivers), Yazoo, Homochitto, and Red Rivers. The streams drain wholly or in part the following States: Arkansas, Colorado, Kansas, Kentucky, Louisiana, Mississippi, Missouri, New Mexico, Oklahoma, Tennessee, and Texas.

VIII. *Western Gulf of Mexico Drainage Basins.*—Include all streams draining into the western Gulf of Mexico and into the Rio Grande. Principal streams flowing into the Gulf of Mexico above the mouth of the Rio Grande: Sabine, Trinity, Brazos, Colorado River of Texas, and Guadalupe. Principal tributaries of the Rio Grande are Rio Hondo, Rio Puerco, Pecos, and Rio San Juan. The streams drain wholly or in part the following States: Colorado, Louisiana, Mexico, New Mexico, and Texas.

IX. *Colorado River Basin.*—Includes the Colorado and its tributaries, of which the most important are Green River (considered the continuation of the Colorado), Grand River, Dolores, San Juan, Little Colorado, Virgin, and Gila Rivers. The principal streams flowing into the Green are Newfork, Yampa, Ashley Creek, White River, Duchesne, Lake Fork, and Uinta. The principal tributaries of Grand River are Grand Lake, Frazer River, Williams Fork, Blue River, and Gunnison River. The streams of the Colorado basin drain wholly or in part the following States: Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming.

X. *Great Basin.*—Includes streams which do not discharge into the ocean. The basin is made up of a number of minor basins, of which the most important are Great Salt Lake, Sevier Lake, Humboldt Sink, and Truckee, Walker, Carson, and Owens River, and Honey, Mono, Malheur, Harney, Warner, Abert, Summer, Silver, and Goose Lake basins. The streams of this section drain wholly or in part the following States: California, Idaho, Nevada, Oregon, and Utah.

XI. *California.*—Includes rivers draining into the Pacific Ocean from California. Principal streams: Tia Juana, Sweetwater, San Diego, Bernardo, San Luis Rey, and Los Angeles Rivers; San Joaquin River, whose principal tributaries are Kern, Kings, Merced, Tuolumne, and Stanislaus Rivers; Sacramento River, whose principal tributaries are Pit, Feather, and American; and the following streams flowing into the Pacific Ocean above San Francisco Bay: Russian, Eel, Mad, and Klamath Rivers. With the exception of the Klamath River, which receives a drainage from a small area in Oregon, all the streams in this division are entirely in California.

XII. *North Pacific Coast.*—Includes streams flowing into the Pacific Ocean from Oregon and Washington. Most important of these are Rogue, Umpqua, and Columbia Rivers and streams flowing into Puget Sound. The principal tributaries of the Columbia are Clark Fork, Kootenai, Spokane, Wenatchee, Yakima, Snake, Bruneau, Boise, Walla Walla, Umatilla, John Day, Deschute, Hood, and Willamette Rivers. The following streams flow into Puget Sound: Nisqually, Puyallup, White, Snoqualmie, and Skagit. The streams of this division drain wholly or in part the following States: Idaho, Montana, Nevada, Oregon, Utah, Washington, and Wyoming.

The accompanying map shows the outlines of the above-described drainage basins.

The engineer is fortunate, indeed, if he can find monthly run-off records for a number of years. When such records are not available it often happens that isolated measurements have been made which will give some idea of the run-off. If no measure-

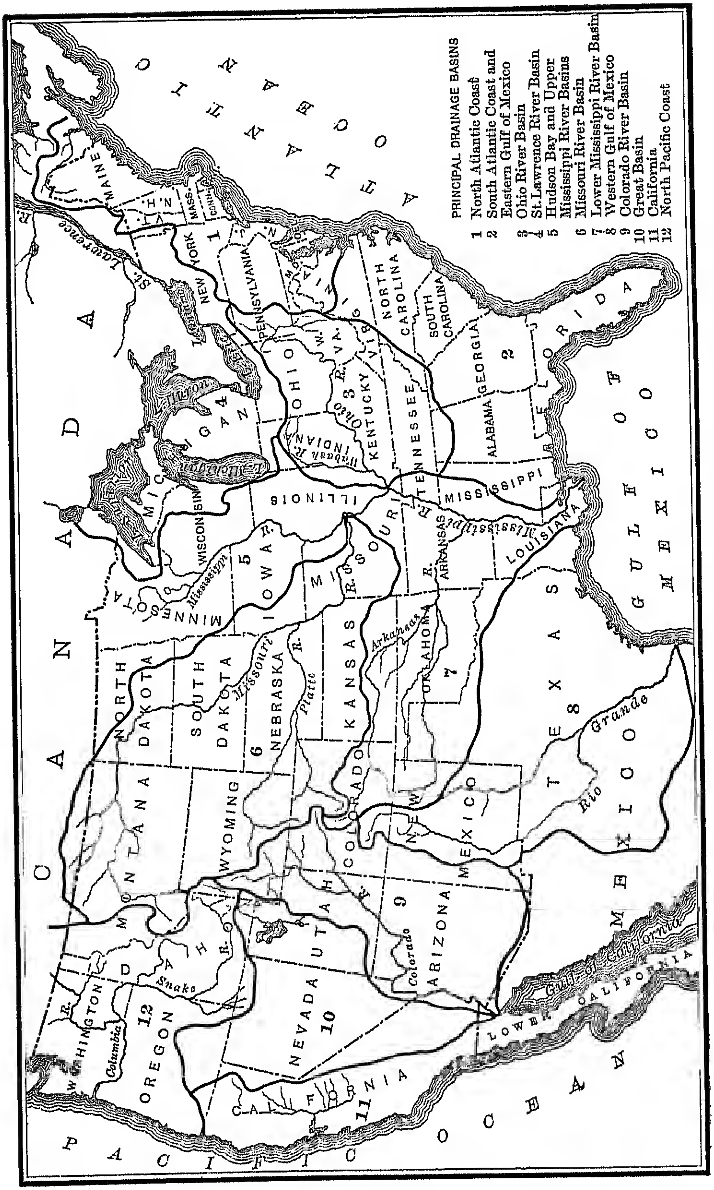


FIG. 1.—Outline Map of Principal Drainage Basins in the United States.

TABLE 2

ANNUAL PRECIPITATION, IN INCHES. NORTH PACIFIC STATES AND NORTHERN ROCKY MOUNTAIN PLATEAU

Year	Salt Lake City, Utah	Winnemucca, Nev.	Tehama, Cal.	Roseburg, Oreg.	Boise, Idaho	Portland, Oreg.	Olympia, Wash.	Spokane, Wash.	Helena, Mont.	Assinniboine, Mont. Harve, Mont.	Annual means	Five-year means
1872.....	.....	6.03	10.10	.....	17.93	46.90	.....	.....	.....	.....	20.24	21.40
1873.....	.....	5.90	13.58	.....	17.74	50.52	.....	.....	.....	.....	21.94	21.90
1874.....	.....	9.73	9.58	.....	14.97	46.17	.....	.....	.....	.....	20.11	22.40
1875.....	23.64	9.58	12.44	.....	13.76	60.08	.....	.....	.....	.....	23.90	23.47
1876.....	21.28	5.67	16.15	.....	11.12	54.94	.....	.....	.....	.....	25.83	25.12
1877.....	16.35	6.47	12.91	.....	13.80	58.30	.....	.....	.....	.....	25.57	27.88
1878.....	19.75	6.77	26.78	36.92	10.21	47.70	63.34	.....	.....	.....	30.21	28.05
1879.....	13.11	9.36	16.32	45.03	17.63	62.22	73.44	.....	.....	.....	33.87	28.43
1880.....	10.94	6.13	12.01	31.44	10.66	51.87	62.77	.....	.....	12.18	24.75	28.49
1881.....	16.88	11.91	9.87	43.68	18.56	58.05	65.56	22.68	19.94	15.54	27.77	26.54
1882.....	15.98	10.46	14.97	34.77	14.43	67.24	51.59	25.99	10.32	12.76	25.85	24.70
1883.....	14.24	8.40	11.01	22.48	15.27	51.45	41.61	14.37	10.55	15.10	20.45	24.01
1884.....	17.52	18.38	21.38	29.19	21.05	38.31	35.58	20.56	19.18	25.67	24.68	22.73
1885.....	19.69	11.80	18.37	30.91	12.56	39.59	41.95	19.01	10.99	8.37	21.32	22.54
1886.....	18.89	8.16	12.02	35.17	12.23	38.76	48.13	15.86	12.63	11.48	21.33	22.83
1887.....	11.66	8.05	11.91	37.34	11.34	54.17	61.78	20.10	14.05	18.94	24.93	21.86
1888.....	13.62	4.89	23.94	31.19	11.09	88.76	45.54	17.69	10.14	.....	21.87	21.50
1889.....	18.46	5.75	39.26	28.12	10.95	31.76	33.75	14.27	6.71	9.40	19.84	22.64
1890.....	10.33	11.27	14.60	34.65	12.53	40.29	35.70	16.57	8.80	10.37	19.51	22.38
1891.....	15.92	9.68	23.04	46.90	13.31	47.41	58.73	16.69	19.39	19.41	27.05	23.10
1892.....	14.08	7.85	46.26	28.88	11.75	33.58	49.41	16.78	15.27	12.40	23.63	24.06
1893.....	17.35	7.35	26.46	37.86	13.87	39.03	61.62	22.00	15.48	13.31	25.48	24.04
1894.....	15.27	10.12	20.92	44.29	14.12	39.32	58.57	17.84	11.17	14.49	24.61	23.34
1395.....	11.95	6.84	25.55	29.92	7.90	30.76	46.60	13.46	10.69	10.94	19.41	24.56
1896.....	18.42	11.08	27.68	43.69	22.95	44.13	65.46	20.32	15.38	16.48	28.56	23.38
1897.....	16.74	6.66	17.40	34.83	16.98	43.01	58.50	23.84	16.16	13.30	24.74	23.68
1898.....	16.09	7.08	8.54	25.93	.....	33.90	42.22	13.08	17.40	12.11	19.59	24.18
1899.....	17.57	8.47	23.15	42.97	14.81	42.21	62.22	20.08	11.78	17.88	26.11	23.10
1900.....	11.53	7.43	21.17	29.74	12.77	38.22	56.37	18.72	11.62	11.43	21.90	23.29
1901.....	16.08	8.73	20.76	34.37	9.59	41.05	55.08	15.99	14.71	15.03	23.14	23.71
1902.....	11.41	4.99	25.65	39.58	12.15	50.15	70.77	19.23	10.09	12.94	25.70	23.50
1903.....	14.62	6.53	20.26	29.50	9.55	35.62	56.88	16.55	11.36	16.08	21.69	22.83
1904.....	16.31	9.44	29.51	43.42	14.08	46.37	61.67	13.97	7.49	8.61	25.09	23.46
1905.....	14.23	6.42	19.67	21.14	9.77	34.10	46.43	16.68	10.08	6.76	18.52	23.21
1906.....	21.28	10.50	33.68	30.21	14.19	43.29	63.86	17.60	14.28	14.13	26.30	22.90
1907.....	19.22	11.35	17.73	42.12	15.92	42.89	51.68	17.69	12.74	13.28	24.46	22.30
Mean..	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	23.89	.....

ments whatever are available, the best that can be done as a preliminary step is to measure the slope and cross-section of the stream and calculate the probable maximum run-off, and compare the drainage basin with others of known run-off by means of rainfall records which may be obtained from the publications of the U. S. Weather Bureau. Tables 2 to 8 compiled by the

TABLE 3

ANNUAL PRECIPITATION, IN INCHES. NORTHERN ROCKY MOUNTAIN SLOPE

Year	Dodge City, Kans.	Denver, Colo.	North Platte, Nebr.	Omaha, Nebr.	Pierre, S. Dak. Sully, S. Dak.	Bismarck, N. Dak.	Pembina, Minn. St. Vincent, Minn.	Moorhead, Minn. Breckenridge, Minn.	Williston, N. Dak. Fort Buford, N. Dak.	Cheyenne, Wyo.	Annual means	Five-year means
1872.....	.....	18.05	.....	32.48	19.42	.....	14.86	.....	16.80	13.48	19.17	17.80
1873.....	.....	11.81	.....	27.04	14.62	.....	13.19	27.39	20.76	10.01	17.83	18.00
1874.....	.....	13.46	.....	25.75	16.24	.....	12.64	27.63	7.58	9.71	16.14	18.22
1875.....	10.78	17.25	15.35	42.89	13.99	27.52	13.53	19.59	14.85	12.10	18.79	18.91
1876.....	15.40	20.12	11.84	32.51	19.54	30.92	25.75	18.13	12.34	5.03	19.16	19.90
1877.....	27.89	16.38	25.47	40.95	22.92	17.68	21.67	29.38	12.29	11.71	22.63	20.45
1878.....	17.96	15.51	18.62	37.05	20.19	20.23	33.83	35.72	16.11	12.64	22.79	20.63
1879.....	15.43	10.86	20.06	30.31	23.50	22.61	19.31	19.76	19.67	7.34	18.89	21.22
1880.....	18.12	9.58	17.48	28.52	16.66	19.75	27.35	27.60	13.25	8.38	19.67	20.59
1881.....	33.55	12.78	22.93	45.74	14.85	15.76	19.26	29.48	14.90	11.88	22.11	20.74
1882.....	13.14	14.49	17.95	37.68	12.20	21.33	22.48	34.01	12.73	8.64	19.47	21.26
1883.....	28.50	19.49	30.01	48.92	19.91	15.66	17.88	24.96	10.82	19.24	23.54	21.39
1884.....	30.36	15.07	13.53	47.68	11.97	23.36	21.81	28.50	7.37	15.54	21.52	20.49
1885.....	23.71	15.95	22.03	36.68	20.82	13.08	17.37	22.68	15.56	15.11	20.30	20.06
1386.....	19.35	15.07	13.10	22.67	16.00	13.26	29.24	26.76	10.24	10.36	17.61	18.73
1887.....	15.71	12.49	21.68	19.92	14.26	16.33	23.36	21.97	15.43	11.82	17.30	17.54
1888.....	22.94	9.51	17.46	24.22	14.77	16.51	17.99	16.50	14.70	14.51	16.91	16.68
1889.....	19.17	14.75	20.66	22.97	15.29	11.03	11.75	17.07	8.46	14.65	15.58	17.83
1890.....	11.72	9.33	12.71	22.08	13.28	16.75	23.50	21.79	14.24	14.47	15.99	18.16
1891.....	32.34	21.43	23.36	34.92	13.18	20.50	25.93	24.31	18.98	18.97	23.39	17.88
1892.....	19.66	15.02	20.37	29.44	18.81	18.17	15.34	24.94	14.26	13.50	18.95	17.81
1893.....	10.12	8.48	13.16	26.66	14.56	13.74	20.07	23.58	15.45	9.22	15.50	18.14
1894.....	12.60	15.09	11.21	17.82	7.82	14.32	20.29	22.43	17.76	12.98	15.23	17.63
1895.....	20.31	16.12	14.58	21.69	16.85	16.92	20.60	17.38	17.07	14.76	17.63	17.48
1896.....	19.87	11.84	16.52	35.90	17.35	16.64	.....	26.80	22.04	20.79	20.86	17.91
1897.....	21.58	15.37	17.09	21.30	18.84	14.33	.....	25.80	12.19	17.25	18.19	18.42
1898.....	31.46	12.98	15.54	28.84	10.65	13.67	.....	19.83	14.44	13.05	17.66	18.78
1899.....	28.45	9.33	13.99	26.74	20.00	15.47	16.01	20.64	12.61	14.18	17.74	18.20
1900.....	20.76	15.29	12.29	31.20	16.81	17.88	21.06	27.50	15.81	16.09	19.47	18.66
1901.....	16.06	9.10	16.44	25.08	17.04	15.59	16.50	30.16	18.36	14.99	17.93	19.01
1902.....	17.70	13.35	26.27	30.48	20.04	15.95	18.97	29.12	16.85	16.50	20.52	19.10
1903.....	15.27	9.50	18.36	33.43	19.53	17.96	21.64	28.29	17.69	12.25	19.39	19.64
1904.....	17.19	14.05	23.17	25.48	9.15	14.17	27.81	26.36	9.44	15.72	18.21	20.70
1905.....	25.96	17.68	26.81	29.38	20.46	17.19	18.70	31.48	10.66	22.68	22.15	19.93
1906.....	32.54	16.84	27.99	27.59	22.06	18.22	21.21	26.00	22.01	17.65	23.21	19.40
1907.....	18.26	11.83	19.61	24.60	14.02	16.55	16.31	23.02	10.18	12.34	16.67	18.80
Mean..	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	19.11	.....

Weather Bureau contain valuable general information in regard to rainfall. If the project has any considerable size or importance, nothing short of monthly run-off records for a series of years will justify its construction. This is fully borne out by the numerous failures of irrigation schemes because of insufficient water and other cases where failure was avoided only by the construction of expensive storage works.

TABLE 4

ANNUAL PRECIPITATION, IN INCHES. LAKE REGION AND CENTRAL VALLEYS

Year	Alpena, Mich.	Cleveland, Ohio	Cincinnati, Ohio	Indianapolis, Ind.	Cairo, Ill.	St. Louis, Mo.	Des Moines, Iowa	Chicago, Ill.	St. Paul. Minn.	Duluth, Minn.	Annual means	Five-year means
1872.....	.....	34.39	34.68	34.12	26.52	30.47	.....	29.07	29.72	25.63	30.58	36.95
1873.....	31.10	41.33	41.38	52.83	50.86	45.50	.....	36.41	34.75	34.32	40.96	37.50
1874.....	25.18	33.39	37.45	43.92	47.58	37.88	.....	28.63	35.51	26.43	35.11	38.34
1875.....	37.27	36.91	42.58	54.58	52.93	43.00	.....	38.06	30.66	35.71	41.30	39.64
1876.....	37.62	41.19	52.62	57.56	55.60	48.46	.....	36.48	23.67	40.40	43.78	39.51
1877.....	41.00	33.13	34.65	39.08	39.47	41.43	.....	41.01	28.80	35.23	37.09	40.09
1878.....	38.48	53.51	41.62	38.62	41.76	40.83	.....	41.95	22.78	43.39	40.33	40.28
1879.....	39.97	41.52	51.60	42.88	45.41	25.70	32.82	30.71	32.39	37.17	38.02	40.17
1880.....	43.63	37.38	54.67	50.99	49.56	34.66	36.66	37.32	29.76	47.68	42.23	41.51
1881.....	45.61	34.96	47.24	48.74	32.18	37.37	56.81	44.18	39.16	45.44	43.17	41.85
1882.....	45.10	39.98	52.12	53.68	61.58	43.15	47.60	41.34	23.14	30.32	43.80	41.66
1883.....	35.32	41.13	52.35	54.12	52.54	40.10	39.69	45.86	26.70	32.57	42.04	40.38
1884.....	35.53	33.26	39.28	39.99	51.66	40.64	41.14	34.61	26.11	28.17	37.04	38.28
1885.....	34.71	39.93	33.94	39.51	31.99	45.59	35.03	44.37	25.33	28.24	35.06	35.77
1886.....	40.12	27.34	31.35	39.88	37.98	44.34	29.53	26.77	22.89	26.71	32.69	34.12
1887.....	37.88	35.36	35.08	33.08	26.75	35.30	24.60	29.13	25.85	28.97	31.20	32.77
1888.....	29.36	32.57	34.88	41.36	41.90	41.17	31.15	30.86	25.86	29.02	33.81	33.31
1889.....	31.32	32.57	30.92	38.41	37.74	33.16	25.90	34.95	16.96	21.06	30.30	33.17
1890.....	31.35	47.82	47.70	54.87	50.53	37.63	24.74	32.69	23.38	34.99	38.57	34.24
1891.....	31.61	34.18	38.44	38.23	39.56	30.53	30.14	26.54	21.74	28.83	31.98	34.51
1892.....	32.15	36.51	31.95	39.77	38.71	41.62	38.42	36.56	32.55	37.11	36.54	35.92
1893.....	33.35	33.88	44.00	39.35	48.79	39.33	25.64	27.47	25.95	34.18	35.19	31.90
1894.....	30.88	27.73	26.59	31.13	30.51	27.44	20.06	27.46	25.80	25.74	27.33	32.28
1895.....	21.59	26.84	29.33	33.54	33.57	31.20	26.80	32.38	24.26	25.04	28.46	32.20
1896.....	30.14	36.68	34.48	39.84	39.36	37.55	37.09	33.14	34.73	36.20	35.89	32.55
1897.....	32.59	24.54	43.89	42.15	44.10	40.17	27.07	25.85	30.51	30.34	34.12	33.28
1898.....	34.07	32.54	38.97	44.10	48.66	49.20	28.33	33.77	25.34	34.34	36.93	33.88
1899.....	29.93	24.53	34.69	36.87	42.42	34.61	26.73	26.49	27.54	26.41	31.02	32.05
1900.....	23.03	25.83	27.78	38.45	36.89	29.51	38.46	28.65	34.22	31.45	31.43	32.47
1901.....	25.23	38.71	17.99	30.33	31.68	24.80	19.77	24.52	25.75	28.78	26.76	31.77
1902.....	29.02	39.89	37.30	37.70	33.07	38.43	42.01	37.57	31.75	35.53	36.23	31.90
1903.....	31.54	35.41	34.69	32.46	32.91	33.81	31.43	28.09	37.88	35.88	33.41	32.53
1904.....	24.68	34.56	29.54	45.42	32.00	33.71	28.43	26.14	34.11	28.32	31.69	34.27
1905.....	28.14	31.90	38.69	33.29	39.48	38.54	37.50	35.36	30.76	32.00	34.56	34.03
1906.....	35.22	31.62	40.83	37.47	46.92	35.52	29.44	30.87	33.21	33.67	35.48	33.70
1907.....	22.68	34.76	44.56	38.56	45.58	41.39	34.02	35.10	23.07	30.62	35.03	33.20
Mean..	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	35.55	.....

In case good records are not available, and the project appears from other considerations to be a feasible one, measuring stations should be established and rain gages installed at convenient points on the irrigable area and drainage basin. If the stream is a very small one, a weir may be used for measuring the flow, but if this is not possible, a current meter station should be established. In either case, a reliable local resident should be employed to

TABLE 5

ANNUAL PRECIPITATION, IN INCHES. NORTH ATLANTIC STATES AND NEW ENGLAND

Year	Eastport, Me.	Burlington, Vt.	Boston, Mass.	New York, N. Y.	Albany, N. Y.	Buffalo, N. Y.	Pittsburg, Pa.	Philadelphia, Pa.	Washington, D. C.	Norfolk, Va.	Annual means	Five-year means
1872.....	.....	32.25	50.62	45.78	.....	31.25	31.91	48.36	30.86	56.95	41.00	41.90
1873.....	.....	25.92	54.53	39.98	.....	44.63	41.42	55.28	45.70	55.43	45.36	41.97
1874.....	42.56	31.94	43.52	39.84	37.93	30.44	39.42	46.25	34.58	50.41	39.69	42.05
1875.....	45.42	26.94	50.15	45.19	38.25	31.44	34.05	40.22	41.11	50.97	40.37	42.66
1876.....	57.99	27.53	48.96	47.40	38.19	29.26	37.01	47.39	47.96	46.54	43.82	43.58
1877.....	50.62	33.17	51.49	40.94	36.09	34.48	34.72	37.26	52.59	69.13	44.05	42.87
1878.....	51.37	41.45	65.53	46.66	49.37	60.24	38.76	34.53	60.09	51.87	49.99	42.20
1879.....	43.48	24.27	45.67	36.21	38.66	30.47	37.02	36.75	32.83	35.88	36.12	41.28
1880.....	42.44	25.21	37.30	37.34	32.54	39.26	31.97	33.58	38.83	51.84	37.03	40.86
1881.....	55.98	20.99	52.63	40.40	36.34	35.95	37.30	30.21	42.20	40.06	39.21	39.47
1882.....	47.18	25.64	43.82	46.61	33.76	33.82	38.63	45.58	46.79	57.67	41.95	41.20
1883.....	53.17	.....	35.48	38.83	39.37	38.07	43.17	39.17	45.71	54.30	43.03	42.13
1884.....	64.53	33.37	49.18	55.34	38.90	37.07	34.82	39.34	49.96	45.05	44.76	42.85
1885.....	54.06	33.64	45.10	42.12	34.39	52.36	34.12	33.35	44.84	43.25	41.72	42.39
1886.....	.....	28.47	42.14	46.73	34.01	44.85	39.21	37.24	58.17	54.33	42.79	42.79
1887.....	46.96	31.13	33.75	46.63	39.70	31.55	41.95	42.17	35.08	47.74	39.67	43.49
1888.....	53.25	33.97	45.89	52.95	44.66	33.87	39.89	44.06	45.05	56.64	45.02	44.14
1889.....	42.26	38.21	39.82	58.68	39.51	40.07	41.37	50.60	61.33	70.72	48.26	43.57
1890.....	45.02	38.51	45.93	52.30	44.89	46.55	50.61	34.02	41.59	50.22	44.96	43.43
1891.....	36.44	39.12	39.70	41.44	41.68	30.74	38.28	38.19	52.95	50.63	39.92	42.39
1892.....	32.20	42.24	37.02	38.90	34.83	45.87	32.66	34.78	42.34	49.24	39.01	39.80
1893.....	29.87	29.04	41.84	53.01	35.39	38.64	37.84	37.65	36.71	57.90	39.79	37.56
1894.....	22.84	22.96	36.62	44.17	35.11	38.92	28.17	40.34	30.85	53.09	35.31	35.82
1895.....	32.88	28.69	40.17	35.73	29.80	32.02	27.50	31.01	34.25	45.41	33.75	36.24
1896.....	31.54	28.38	37.55	37.99	27.88	37.29	44.35	32.15	31.16	44.22	31.25	36.68
1897.....	39.57	43.44	40.77	44.27	40.79	37.72	35.08	42.04	44.58	42.66	41.09	36.92
1898.....	45.16	31.78	49.86	45.12	38.77	33.50	35.76	49.23	37.72	53.14	42.00	37.79
1899.....	36.44	37.25	34.69	42.06	28.92	29.39	33.85	39.96	44.02	38.41	36.50	39.90
1900.....	47.35	34.24	44.05	41.78	30.56	35.93	25.73	40.91	41.20	39.34	38.11	39.65
1901.....	41.61	33.88	48.72	47.06	40.53	35.49	40.76	45.54	41.75	42.61	41.80	39.29
1902.....	41.41	38.36	33.93	47.07	37.48	32.91	32.22	49.76	46.58	38.48	39.82	39.47
1903.....	36.67	32.86	41.97	48.60	34.09	37.95	38.81	41.50	43.55	46.10	40.21	39.38
1904.....	38.89	29.71	39.64	41.57	31.26	35.83	33.76	39.76	40.84	42.60	37.39	39.08
1905.....	31.88	34.73	32.08	44.48	26.98	35.85	35.19	41.61	50.64	43.29	37.67	38.97
1906.....	39.49	29.87	40.69	41.82	32.51	33.63	31.29	51.87	52.92	49.23	40.33	38.40
1907.....	44.42	29.67	37.56	45.28	33.63	34.97	34.86	48.74	44.66	38.72	39.25	38.10
Mean..	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	40.61	.....

read the gage daily, recording the readings on suitable blanks furnished for the purpose, or a recording gage may be established which will give a continuous record of the height of water in the form of a diagram.

The rain gage consists of a metal cylinder having a funnel-shaped top leading to a smaller cylinder inside having a cross-

TABLE 6

ANNUAL PRECIPITATION, IN INCHES. EAST GULF STATES

Year	Hatteras, N. C.	Charleston, S. C.	Jacksonville, Fla.	Key West, Fla.	New Orleans, La.	Galveston, Tex.	Montgomery, Ala.	Augusta, Ga.	Memphis Tenn.	Fort Smith, Ark.	Annual means	Five-year means
1872.....	.....	57.06	57.17	31.77	60.68	41.72	.....	55.17	43.95	.....	49.65	53.25
1873.....	.....	62.15	60.65	32.75	65.55	58.91	64.00	48.50	56.20	.....	56.09	53.60
1874.....	.....	62.51	48.31	32.75	62.74	49.39	51.93	57.19	45.71	.....	51.32	54.62
1875.....	68.26	50.97	57.60	36.35	85.73	58.48	58.16	54.68	57.02	.....	58.58	57.50
1876.....	65.78	78.42	55.28	37.95	67.25	50.92	59.74	46.16	55.49	.....	57.44	58.33
1877.....	102.04	78.11	50.58	38.15	63.09	66.87	50.26	53.97	73.50	.....	64.06	57.99
1878.....	77.18	77.44	60.42	49.03	66.16	60.90	55.40	46.34	49.34	.....	60.25	57.89
1879.....	70.72	50.29	47.18	58.54	51.27	26.93	48.46	40.99	52.29	.....	49.63	57.04
1880.....	92.64	46.69	65.51	33.41	69.83	50.97	54.22	47.91	61.67	.....	58.09	55.36
1881.....	58.81	43.20	54.69	53.10	64.01	53.28	53.81	54.77	42.84	.....	53.17	53.80
1882.....	66.60	57.01	53.26	41.86	50.18	57.68	54.75	49.62	71.05	.....	55.67	54.81
1883.....	76.96	51.35	53.34	48.24	69.85	41.11	39.71	39.90	57.14	46.65	52.43	54.13
1884.....	66.41	60.22	55.02	33.05	60.01	62.98	48.61	45.10	64.69	50.63	54.67	53.84
1885.....	68.02	67.93	82.00	34.03	64.18	62.56	58.89	40.67	37.41	31.61	54.73	51.33
1886.....	54.72	35.94	54.86	30.13	54.83	40.97	56.25	46.04	57.72	35.33	46.58	51.92
1887.....	55.07	44.69	58.60	43.62	64.97	43.43	44.74	45.09	42.52	38.69	48.14	50.91
1888.....	56.73	49.46	53.13	35.58	83.13	65.88	61.39	49.88	46.82	50.97	55.40	50.12
1889.....	67.24	52.15	46.22	52.67	48.45	37.52	45.62	49.25	44.67	43.20	49.60	49.92
1890.....	55.51	47.84	47.52	42.87	42.17	47.80	48.18	42.98	68.28	64.63	50.78	49.78
1891.....	59.50	45.50	41.34	39.75	38.62	41.51	51.05	47.76	51.31	40.49	45.68	48.27
1892.....	52.88	53.32	41.89	24.91	56.91	24.78	69.85	39.27	61.46	49.35	47.46	48.38
1893.....	53.80	70.99	58.23	22.00	48.02	35.43	47.48	48.91	44.45	44.70	47.85	47.82
1894.....	57.85	57.81	56.84	42.34	54.44	40.64	41.35	55.54	54.52	41.21	50.15	46.33
1895.....	69.28	55.18	46.80	29.19	56.44	38.91	43.45	52.10	38.59	49.87	47.98	46.25
1896.....	45.25	47.78	40.19	25.72	49.68	23.71	45.82	43.45	35.00	25.70	48.23	45.94
1897.....	58.82	56.65	60.70	46.46	43.47	29.24	46.25	51.83	46.03	41.91	47.54	44.43
1898.....	48.20	46.42	45.71	43.39	49.00	42.00	39.75	43.99	48.58	51.12	45.82	45.21
1899.....	61.88	44.33	38.57	29.55	31.07	41.76	50.63	48.74	38.99	40.27	42.58	46.43
1900.....	45.65	38.10	53.85	48.81	56.33	78.39	59.92	51.22	47.42	39.05	51.87	45.46
1901.....	50.11	32.70	54.22	37.02	57.73	51.33	52.24	50.94	34.58	22.77	44.36	45.42
1902.....	40.13	37.22	55.52	38.61	41.61	37.67	48.62	41.79	50.32	35.12	42.66	44.76
1903.....	48.87	42.86	52.03	30.36	57.18	52.47	48.99	51.83	36.17	35.46	45.62	44.17
1904.....	40.97	37.88	49.17	37.98	43.69	42.65	37.00	29.54	42.56	31.39	39.28	44.63
1905.....	41.66	34.85	55.77	41.84	80.07	48.60	47.23	40.92	55.85	42.50	48.93	44.58
1906.....	53.94	48.62	46.86	48.53	41.59	31.16	50.13	53.91	54.31	42.50	46.66	44.55
1907.....	44.56	31.71	45.07	26.65	66.32	43.93	49.83	38.93	41.55	35.58	42.41	44.40
Mean..	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	50.04	.....

sectional area of one-tenth that of the larger cylinder, so that the depths of water accumulated in the smaller cylinder magnify the actual precipitation ten times, and thus enable very small rainfalls to be accurately measured. The water depth in the small cylinder is measured at the end of each rain by a cedar stick graduated to inches and tenths of inches. Standard rain gages are generally furnished by the Weather Bureau

TABLE 7

ANNUAL PRECIPITATION, IN INCHES. WEST GULF STATES AND SOUTHERN ROCKY MOUNTAIN SLOPE

Year	San Antonio, Tex.	Gilmer, Tex. Golindo, Tex. Palestine, Tex.	Fort Griffin, Tex. Fort Condo, Tex. Abilene, Tex.	Fort Elliott, Tex. Amarillo, Tex.	Fort Sill, Okla.	Santa Fé, N. Mex.	Fort Bayard, N. Mex.	El Paso, Tex.	Fort Ringgold, Tex.	Brownsville, Tex.	Annual means	Five-year means
1872...	26.17	46.49	20.58	.....	25.14	9.87	13.61	7.68	14.76	21.67	20.78	21.20
1873...	34.02	52.68	12.03	.....	33.80	9.73	11.62	5.77	19.63	26.66	22.88	21.80
1874...	41.55	43.06	26.34	.....	28.89	19.93	20.38	7.24	20.33	26.85	26.06	22.33
1875...	21.95	36.93	18.76	.....	37.39	18.97	19.66	6.48	11.94	18.36	21.16	23.33
1876...	.....	39.32	19.71	.....	24.42	15.07	18.94	9.46	13.26	25.81	20.75	24.35
1877...	30.29	31.89	36.61	.....	43.11	13.15	13.12	.....	12.53	25.86	25.82	22.87
1878...	39.60	31.41	29.77	.....	25.55	19.52	18.92	.....	22.53	36.35	27.96	23.44
1879...	22.80	.....	18.93	.....	20.86	11.44	13.77	6.81	19.94	34.73	18.66	24.45
1880...	41.91	.....	28.71	16.79	33.75	9.89	16.90	14.37	15.77	38.07	24.02	24.38
1881...	26.78	36.00	20.86	16.16	28.22	.....	30.82	18.17	23.40	31.74	25.79	23.91
1882...	36.39	57.20	21.76	24.76	31.13	11.37	19.27	8.27	11.95	32.56	25.47	26.62
1883...	.....	43.49	21.76	28.21	.....	.....	.....	12.92	16.16	31.02	25.59	27.17
1884...	.....	51.64	35.86	33.91	.....	.....	.....	18.30	12.77	40.91	32.23	26.63
1885...	32.92	41.85	21.37	37.07	33.05	14.89	.....	7.31	20.64	31.83	26.77	26.83
1886...	26.22	33.21	19.14	23.05	19.57	15.90	11.84	8.06	14.01	60.06	23.11	27.15
1887...	20.13	38.04	24.63	22.83	34.17	13.38	12.39	6.76	32.27	59.87	26.45	25.45
1888...	40.55	59.66	30.58	16.51	35.72	12.03	13.07	9.79	21.32	32.58	27.18	25.13
1889...	38.96	46.43	25.23	19.40	29.29	7.89	6.59	7.10	21.67	34.61	23.72	23.85
1890...	29.79	52.06	28.50	15.41	31.08	12.88	15.86	8.49	13.43	25.55	20.20	23.24
1891...	30.04	45.27	17.57	17.15	32.76	16.79	10.30	2.22	16.60	28.25	21.70	21.39
1892...	25.81	61.19	28.48	15.60	34.32	11.62	8.80	5.32	19.25	.....	23.38	20.62
1893...	18.24	30.58	16.27	17.23	24.19	14.94	15.47	10.88	17.51	14.36	17.97	21.46
1894...	21.75	46.05	24.39	15.81	24.14	13.31	8.67	4.24	21.80	18.33	19.85	21.41
1895...	26.07	43.72	35.30	24.79	29.17	20.24	14.45	10.20	21.11	19.20	24.42	20.98
1896...	34.09	38.40	20.74	24.28	17.12	14.28	18.85	9.79	17.10	19.41	21.41	21.47
1897...	15.92	39.48	23.30	19.16	26.29	20.40	18.00	12.41	19.19	18.14	21.28	22.09
1898...	22.49	42.05	22.13	22.54	37.56	12.97	16.21	6.16	9.75	12.31	20.42	22.23
1899...	19.65	47.71	23.41	27.39	46.51	10.05	10.78	7.30	17.48	19.50	22.98	21.53
1900...	37.19	44.32	32.11	24.40	36.47	15.89	12.61	7.95	.....	14.99	25.10	21.76
1901...	16.44	41.22	15.71	24.42	16.07	17.41	8.94	8.68	11.32	19.20	17.94	22.13
1902...	24.79	39.76	27.05	23.11	46.79	13.36	15.67	10.15	5.28	17.62	22.36	22.14
1903...	33.11	39.48	26.53	20.28	18.68	9.79	12.33	11.63	22.85	26.78	22.15	23.34
1904...	29.38	32.37	17.80	21.33	30.32	14.19	.....	11.30	28.55	23.10	23.15	24.84
1905...	32.59	46.30	33.06	32.32	50.08	17.22	.....	17.80	20.98	29.35	31.08	24.56
1906...	20.42	32.94	29.05	24.92	38.78	16.60	.....	14.99	.....	26.12	25.48	23.70
1907...	27.77	38.01	18.33	18.09	.....	15.15	.....	8.41	.....	.....	20.96	22.80
Mean	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	23.50	.....

free of cost, provided the records are regularly supplied to the bureau.

The weir station is applicable only to very small streams. Three standard types of weirs are used for measuring water: (1) The Cippoletti weir, having the sides inclined on a slope of one horizontal to four vertical. (2) The contracted rectangular

TABLE 8

ANNUAL PRECIPITATION, IN INCHES. SOUTHERN PACIFIC STATES AND SOUTHERN ROCKY MOUNTAIN PLATEAU

Year	Yuma, Ariz.	Prescott, Ariz.	Tucson, Ariz.	Reno, Nev.	Humbolt, Nev.	Chico, Cal.	San Francisco, Cal.	Merced, Cal.	Auburn, Cal.	San Diego, Cal.	Annual means	Five-year means
1872.....	.....	16.66	.....	4.11	4.41	26.48	22.45	10.33	35.03	6.07	15.69	14.00
1873.....	.....	12.14	.....	2.75	5.04	19.38	18.55	10.00	26.81	13.01	13.46	14.40
1874.....	.....	.....	.....	5.70	4.47	24.34	22.52	7.76	33.02	10.93	15.53	14.47
1875.....	.....	.....	.....	6.06	4.62	15.41	22.63	12.65	33.99	6.80	14.59	13.29
1876.....	0.94	16.16	14.02	3.59	4.93	21.86	23.54	7.10	31.65	7.24	13.10	14.03
1877.....	3.66	11.09	12.77	5.68	4.52	17.54	11.93	4.30	18.07	8.12	9.77	14.19
1878.....	2.88	15.63	16.66	6.32	6.56	31.16	33.26	10.43	34.94	13.87	17.17	14.10
1879.....	3.29	12.89	12.01	4.02	7.12	25.05	30.76	8.44	45.14	14.71	16.34	14.12
1880.....	0.74	10.02	6.61	6.70	3.85	17.38	30.07	13.81	41.68	10.37	14.12	14.87
1881.....	0.98	15.45	14.92	5.89	7.13	15.53	20.73	8.02	35.54	5.00	13.22	13.66
1882.....	1.78	15.26	15.59	5.48	9.14	17.69	18.67	9.03	32.84	9.74	13.52	14.88
1883.....	3.96	16.13	8.50	3.95	7.08	16.00	15.43	10.18	21.61	8.01	11.09	14.35
1884.....	5.86	26.75	15.03	6.17	4.94	23.19	38.82	23.79	52.41	27.59	22.46	14.28
1885.....	2.72	10.11	5.26	2.95	6.23	20.41	24.90	9.89	26.31	5.73	11.45	14.02
1886.....	5.35	18.78	8.63	4.82	2.64	15.91	20.02	7.83	29.41	15.35	12.87	14.37
1887.....	3.90	17.36	12.95	5.78	3.25	15.44	19.04	6.45	27.77	10.45	12.24	13.67
1888.....	2.95	18.52	10.60	4.60	2.00	19.91	23.03	10.55	24.79	11.57	12.85	14.57
1889.....	4.69	20.83	18.37	6.56	4.21	29.82	36.94	12.78	38.97	16.03	18.92	14.55
1890.....	4.67	21.17	15.04	6.36	11.85	21.78	25.43	11.54	34.04	8.02	15.99	15.31
1891.....	2.67	14.66	7.30	10.45	7.62	19.79	21.11	8.56	26.52	8.99	12.77	15.46
1892.....	3.35	12.90	11.25	11.92	3.78	36.24	22.08	10.03	39.56	9.09	16.02	14.71
1893.....	3.00	14.01	13.26	4.74	3.47	25.49	17.91	9.07	34.77	10.29	13.60	14.17
1894.....	2.95	11.97	7.41	7.27	3.85	30.61	24.32	15.50	43.49	4.35	15.17	15.15
1895.....	1.33	14.50	11.07	5.55	4.53	27.35	17.13	8.36	31.95	11.33	13.31	14.73
1896.....	2.55	16.23	11.39	10.59	6.14	33.78	28.25	14.22	44.76	8.73	17.66	13.78
1897.....	4.18	21.88	10.77	8.00	6.19	20.84	16.40	8.80	32.94	8.93	13.89	13.60
1898.....	2.38	11.89	12.72	5.81	3.99	12.31	9.31	5.69	19.96	4.67	8.87	13.39
1899.....	0.60	10.91	8.38	8.29	4.10	27.30	23.23	11.75	41.86	6.08	14.25	12.77
1900.....	0.85	10.33	7.79	15.17	6.25	20.14	15.33	11.09	30.22	5.77	12.29	12.25
1901.....	3.65	12.97	9.72	11.36	8.24	20.27	19.75	9.30	40.53	9.49	14.53	13.11
1902.....	1.93	14.31	8.60	4.94	4.19	28.04	19.18	9.17	.....	11.49	11.32	13.58
1903.....	0.98	16.74	8.80	6.55	4.46	22.76	18.33	11.03	35.82	6.09	13.16	14.59
1904.....	1.43	15.86	7.85	10.63	8.27	30.39	24.72	12.84	47.55	6.61	16.62	15.98
1905.....	11.41	39.47	24.17	5.69	2.37	24.11	16.24	9.18	24.20	16.36	17.32	17.14
1906.....	5.40	25.13	11.75	11.05	3.92	37.27	26.34	19.65	60.63	14.90	21.50	17.20
1907.....	2.61	20.80	14.09	11.27	4.95	24.15	22.47	15.23	47.26	7.95	17.08	16.00
Mean..	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	14.55	.....

weir, having the sides vertical; and, (3) The suppressed rectangular weir having the sides vertical and flush with the sides of the approach channel. The discharge of the Cippoletti weir is given by the formula $Q = 3.37\ L\ H^{3/2}$ values of which are given in Fig. 36. The discharge of contracted rectangular weirs is given by the formula $Q = 3.33\ (L - .2H)\ H^{3/2}$ values of

which are given in Fig. 37. Neither of these formulas considers velocity of approach, and in order to make them accurate there should be a pool of comparatively still water just above the weir. If a pool does not exist and is impossible of construction, the measured head must be corrected for velocity head when the velocity of approach is greater than 0.5 to 1 foot per second. The formulas for both Cippoletti and contracted rectangular weirs give discharges that are too large when the head on the crest is greater than one-third the crest length, and the error increases as the head increases beyond this ratio, being about 30 per cent for a ratio of head to crest length of 1. If correction for velocity of approach is necessary these weirs generally become undesirable as measuring devices and the suppressed weir is much better. Bazin's formula for this weir automatically corrects for velocity of approach and a direct measurement of the head and height of weir above approach channel is all that is necessary, no matter what the velocity of approach is. One fundamental requirement, however, must be met before this can be accomplished, namely, that the approach channel be of uniform cross-section for some distance above the weir. To this end it is usually necessary to construct an artificial channel which should be capable of being cleaned of silt and débris when necessary.

The proper location and operation of a current-meter station is a larger subject than can be comprehensively discussed here, but a few general points will be considered. The station should be located in a straight and uniform stretch of the stream, and where the water is confined between the banks of the normal channel at all stages. The gage should be located out of the path of all disturbing elements and be of such range as to cover all stages of the river from the lowest to the highest. Measurements are made by wading, from a convenient bridge, or from a cable car established for the purpose. The first method can obviously be used only in shallow streams. If a bridge is located across a section of the river complying with the general requirements for a current-meter station, the gagings can be conveniently made therefrom, and the cost of constructing and maintaining a cable station need not be incurred.

For gagings by wading, the measuring points may be located by rags tied to a wire stretched across the stream. In measurements from a bridge, the points may be located by marks painted on the floor beam or lower chord of the bridge. At cable stations the points are located on the cable by any convenient means. In all cases the measuring points should be permanently fixed.

The current meter consists essentially of a wheel which is caused to rotate by the currents of the flowing water, and a device for determining the number of revolutions of the wheel. Each meter should be rated before it is used, to determine the relation between revolutions of the wheel and velocity of the water. In rating the meter it is driven at different uniform speeds through still water for a given distance, and the number of revolutions counted. The relation of velocity of water to revolutions of the wheels is for all meters practically a linear one, that is, if 60 revolutions per minute correspond to a velocity of 1 foot per second, 120 revolutions per minute correspond to 2 feet per second, etc. Velocities less than 0.3 foot per second can not be measured with a current meter, as it requires a certain small velocity to overcome the inertia of the wheel and start it revolving. Many kinds of current meters have been constructed, but the Price meter, manufactured by W. and L. E. Gurley, Troy, N. Y., is probably best adapted for general use. These meters are made in two general styles—one with an electric device for indicating the revolutions to the ear, and the other with a direct acoustic attachment; in other respects the meters are the same.

The cable should be of iron or steel of sufficient strength to sustain a car and two men, and should be securely anchored at both ends. The car should be about 5 ft. x 3 ft. x 1 ft. deep, attached at each end to a pulley on the cable. If the stream is deep and its velocity high a stay line will be required to hold the meter in position. This line should be located about 100 feet upstream from the cable. The following dimensions * of

* Taken from "River Discharge," by Hoyt and Grover, John Wiley & Sons, New York.

cable are based on a working stress of about 16,000 pounds per square inch.

Span Feet	Diameter Inches	Sag Feet
100	$\frac{1}{2}$	4
200	$\frac{9}{16}$	6
300	$\frac{5}{8}$	8
400	$\frac{3}{4}$	10
500	$\frac{3}{4}$	12
600	$\frac{7}{8}$	12
700	1	14
800	$1\frac{1}{8}$	15

The methods pursued in measuring the flow with current meters in rivers and canals are essentially the same, and will here be considered together. More accurate results are desired and necessary in canal measurements, and fortunately the conditions of flow and cross-sections of channel are favorable in most cases for such increased accuracy. Good measurements on canals should give an accuracy within 2 or 3 per cent, while river measurements are considered good if they give within 5 to 10 per cent of the true discharge.

Soundings, either with a meter or with a special sounding line and weight, should be made at the permanent measuring points. The mean velocity at each of these measuring points should then be determined by means of the current meter, in accordance with one of the approved methods of determining mean velocities. There are five general methods of determining mean velocities in a vertical line with a current meter: (*a*) by taking the velocity at 0.2 and that at 0.8 of the water depth and obtaining one-half the sum; (*b*) by taking the velocity at 0.6 of the water depth; (*c*) by taking the velocities at equal vertical intervals of 0.5 of a foot or more, and obtaining their arithmetical mean, or finding the mean value from a curve derived by plotting the measurements on cross-section paper; (*d*) by taking the velocity near the water surface and using from 0.85 to 0.95 of the result, depending on the depth of water, its velocity, and the nature of the canal bed; and, (*e*) by taking velocity in the vertical line by slowly and uniformly lowering and raising the meter throughout the range of water depth one

or more times. Experiments have shown that the 0.2 and 0.8 method generally gives the most uniform and satisfactory results.

There are two important methods of computing discharges from measurements made by current meters. Both of these methods are based on determining the discharges of the elementary areas between the measuring points and taking their sum. In one of the methods, the discharge is computed separately for each elementary area on the assumption that both the velocity and the water depth vary uniformly from one measuring point to another. This may be termed the straight-line method, and the formula for computing the discharge of the elementary area is as follows:

$$q = \left(\frac{V_a + V_b}{2}\right) \left(\frac{a + b}{2}\right) l;$$

in which a and b are the water depths in feet at two adjacent measuring points, V_a and V_b the respective mean velocities in feet per second at these points, l the distance in feet between the points, and q the discharge in second-feet for the elementary area. This formula is well suited to computing discharges in canals conforming in cross-sections to their original trapezoidal or rectangular dimensions. In the other method, the discharge is computed for consecutive pairs of elementary areas, on the assumption that the velocities and the water depths for three consecutive measuring points each lie on the arc of a parabola. This method might be termed the parabolic method and the formula for computing the discharge for each pair of elementary areas is as follows:

$$q' = \left(\frac{V_a + 4\,V_b + V_c}{6}\right) \left(\frac{a + 4b + c}{6}\right) 2l;$$

in which a, b, and c are the water depths in feet at three consecutive measuring points; V_a, V_b, and V_c the respective mean velocities in feet per second at these points; l the distance in feet between the consecutive points, and q' the discharge in second-feet for the pair of elementary areas. This formula is more particularly applicable to river channels and old canals that have cross-sections conforming in a general way to the arc of a parabola, or to a series of arcs of different parabolas.

The discharge measurements at a current-meter station should be taken at sufficient intervals of gage heights to permit of making accurate velocity, area, and discharge curves. For this purpose it is necessary to get well-distributed measurements from low to high stages. Special precautions are necessary in canal measurements. The canal bed at a well-selected current-meter station is generally permanent in character and a permanent rating curve could be made were it not for the fact that increased vegetable growth in the canal and on its banks, during the irrigation season, together with accumulations of silt, decrease the discharge capacity for all gage heights during the latter part of the irrigation season. This fact must be taken into consideration in computing the quantity of water carried by a canal during the irrigation season. If the canal is cleaned during the season, the relation of discharge to gage height is again disturbed. These changing relations of discharge to gage height are the chief source of errors and difficulties in irrigation-canal hydrography.

In order to determine the discharge at a current-meter station it is necessary to read the gage daily for rivers, and for canals additionally at such times as changes of stage are made. The gages should be read accurately, generally to the nearest hundredth of a foot. The current-meter measurements at a station are interpreted and extended to cover all gage heights at the station by means of curves drawn on cross-section paper. To construct these curves, the discharges in second-feet as computed from individual current-meter discharge measurements, the corresponding mean velocities in feet per second, and the cross-sectional areas in square feet for each measurement are plotted as abscissas, each to a convenient scale, with the common gage heights as ordinates. The most probable area curve is drawn through the area plottings and from this the accuracy of the area computations and of the soundings are checked and, in case of a shifting channel, changes in the rating section are discovered. The most probable velocity curve is drawn through the velocity plottings on the sheet to provide a graphic means of finding inaccuracies in the computations and noting disturbances in the velocity due to obstructions in the channel or changes in the velocity due to increased roughness of the channel

from vegetable growths in the canal. The discharge curve is then drawn through the discharge points on the cross-section paper, giving due weight to the various measurements and to products of the mean velocity and area abscissas for various gage heights throughout the range of depths. Where the conditions of flow have not been changed during the season, it will generally be comparatively easy to draw a satisfactory curve. Where, however, the relation of discharge to gage height has been affected by vegetable growth, or the introduction of other obstructions, these conditions must be given careful consideration and another curve drawn for that part of the season during which

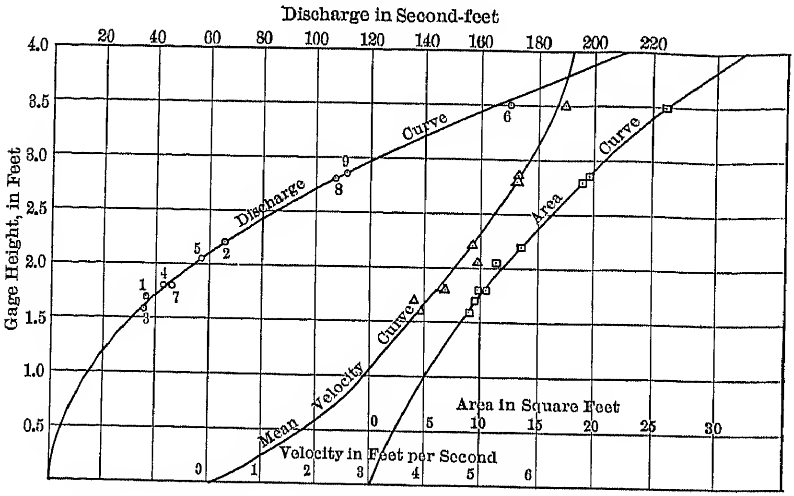


FIG. 2.—Example of Discharge, Mean Velocity, and Area Curves.

such conditions have existed. The discharge curve for these conditions will generally be parallel to the discharge curve for the earlier part of the season when the channel was clean. For the period during which the change is in progress, the discharges must be estimated on the theory of proportion from the two curves constructed for the extreme conditions.

By means of daily gage heights and the rating tables, the daily discharges may readily be compiled, and the summation of these gives the monthly discharges and the total amount of water carried during any period.

Prior Water Rights.—Before the quantity of water available for any project can be determined, it is necessary that the amount and priorities of all vested water rights in the watershed of the proposed project be definitely determined and the rights of all parties fixed in order that the available supply for diversion and storage may be correctly ascertained. This is too large and complex a subject to be discussed here. It will be considered sufficient to say that it may have a large influence on the feasibility of a project. It is well to obtain legal advice in these matters.

Reservoirs Available.—If the examinations previously discussed show that the monthly flow of the stream at the proposed point of diversion after deducting priorities is not sufficient for the needs of the project, means will have to be provided for increasing this flow during the irrigation season, either by storage of the winter flow of the stream in question or by diversion of water from an adjacent watershed. To this end, a careful reconnoissance of the headwaters of the stream is necessary, which should supply approximate data as to possible dam sites, together with the nature of foundations at these sites; the geologic formation of the reservoir bed and capacity of reservoir; the probable flow of the stream at the dam site; materials available for construction, and all other information that might have a bearing on the feasibility of the sites that does not require too much time and expense to ascertain. If no dam or reservoir sites are found on the stream itself, examination should be made of the surrounding country to determine if there are any feasible sites to which a feed canal could be constructed from the main stream or its tributaries. Examination should be made of adjacent watersheds and streams, and the dividing ridges, to ascertain if it would be feasible to divert water from one watershed to the other and the probable quantity of water that could be so diverted.

These examinations must necessarily be of a rough nature, as detailed examinations are usually expensive. The topographic sheets of the U. S. Geological Survey, if available, are of great assistance for this purpose, as are also the surveys made by the engineering departments of the several States.

CHAPTER II

INVESTIGATIONS AND SURVEYS

Water Duty; Quantity Applied to Land.—An examination of an irrigation project necessarily involves a determination of the quantity of water required to mature crops. In most arid regions, irrigation has been practised in one form or another, and the quantity of water actually used in such cases, of which there is generally some record, provides perhaps the best criterion for a determination of the quantity of water required.

Reliable information on the quantity of water actually applied to the land and used for maturing crops is very meagre. This is largely due to the fact that very few projects have been equipped with accurate measuring devices and in many cases the water diverted to the land even when measured has been largely in excess of the requirements, and no record was kept of the quantity wasted. Fortunately, due to the Government's interest in irrigation matters, and because of the increasing scarcity of unappropriated water, accurate records are now being kept on many projects, and in the course of the next few years good data will probably be available.

The quantity of water required for irrigation depends on the amount of rainfall, length of irrigation season, nature of soil, kind of crop, and, to a very large extent, upon the efficiency with which the water is handled. Sandy and gravelly soils require more water than volcanic ash and clayey soils. Hay and vegetables require more water than fruits and grains. Continuous irrigation with a small head of water results in a loss that is avoided when intermittent applications are made with larger heads. The quantity of water applied to the land on some of the Government reclamation projects is contained in the following tabulation:

TABLE 9

WATER USED ON PROJECTS OF THE U. S. RECLAMATION SERVICE

Project	Depth of Water Applied to Land (Feet)						Average Rainfall, Ins.	Length of Irrigation Season	Character of Soil	Principal Crops
	1908	1909	1910	1911	1912	Average		Days		
Salt River, Ariz.	...	...	3.6	4.8	3.5	4.0	8.0	365	Sandy loam.	Fruits, hay, cotton.
Yuma, Ariz.-Cal.	...	5.1	4.3	6.3	4.6	5.1	2.5	365	Rich alluvium, grav. sands.	Fruits, hay, cotton.
Uncompahgre, Colo.	...	3.0	2.9	4.7	4.8	3.8	9.0	214	Sandy gravel & clay loam.	Fruits, hay, vegetables.
Boise, Idaho	...	2.4	1.7	1.8	2.0	2.0	13.4	214	Clayey and sandy loam.	Fruits, hay, veg. & grains.
Minidoka, Idaho	...	...	7.3	4.6	4.3	5.4	12.4	214	Sandy loam & lava ash.	Fruits, hay, veg. & grains.
Huntley, Montana	1.5	2.0	2.0	1.9	1.5	1.8	12.2	153	Heavy clay to sandy loam.	Hay, grain, sugar beets.
Sun River, Montana	...	...	2.3	1.7	1.7	1.9	12.0	153	Sandy loam, clay.	Hay, grain, vegetables.
Flathead, Montana	...	...	2.0	2.0	2.0	2.0	15.0	153	Sandy loam to heavy clay.	Apples, hay, grain, veg.
No. Platte, Neb.-Wyo	1.2	3.1	3.9	4.7	2.2	2.2	15.0	183	Sandy loam.	Hay, grain, vegetables.
Truckee-Carson, Nev.	...	4.9	4.7	4.5	*2.5	4.2	4.0	198	Sand, sandy loam, clay and volcanic ash.	Hay, grain, vegetables.
Carlsbad, New Mex.	2.3	2.3	2.4	2.6	2.9	2.5	15.0	260	Sandy loam.	Fruit, hay, grain, cotton.
Rio Grande, N.Mex.-Texas.	...	...	5.9	5.9	...	5.9	9.5	274	Sandy loam and alluvium.	Fruit, hay, grain.
Klamath, Ore.-Cal.	2.0	1.1	0.9	1.2	1.1	1.3	13.6	153	Sandy loam & volcanic ash.	Fruit, hay, vegetables.
Belle Fourche, S. D.	2.2	1.7	1.9	1.6	1.1	1.7	13.0	163	Sandy loam.	Hay, grain, vegetables.
Lr. Yellowstone, Mon.-N.D.	...	0.7	1.4	1.4	1.2	1.2	16.0	148	Sandy loam & heavy clay.	Hay, grain, vegetables.
Okanogan, Wash.	...	2.7	2.1	*0.9	*1.2	1.7	8.2	123	Sandy loam.	Hay, grain, vegetables.
Tieton, Wash.	...	...	1.9	1.9	2.3	2.0	6.0	153	Volcanic ash.	Fruit, hay, hops.
Sunnyside, Wash.	3.5	3.5	2.8	2.8	3.1	3.1	6.6	214	Vol. ash and sandy loam.	Fruit, hay, hops.
Shoshone, Wyo.	2.6	2.5	2.1	2.2	1.7	2.2	5.6	180	Sandy and clay loam.	Hay, grain, vegetables.
Orland, Cal.	...	...	3.4	3.9	4.0	3.8	17.0	214	Sandy loam.	Fruit and hay.

*More water could have been used to advantage in these years if it had been available.

TABLE 10

DEPARTMENT OF THE INTERIOR. UNITED STATES RECLAMATION SERVICE. WATER DISTRIBUTION FOR 1912

Projects	Area Irrigated, Acres	Total Amount of Water Delivered to Land, Acre-Feet	Acre-Feet Delivered to Farms per Acre Irrigated (Based on total area irrigated during season)													Total Amt. of Water Diverted, Acre-Feet
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	
Ariz., Salt River	159,170	561,000	No report on distribution of water for Salt River project.												3.52	760,326
Ariz.-Cal., Yuma	13,767	63,273	.19	.41	.35	.39	.44	.41	.50	.61	.51	.34	.22	.21	4.58	96,409
Cal., Orland	4,230	16,702	..	..	.05	.28	.67	.83	.79	.76	.29	.30	..	..	3.97	34,084
Colo., Uncompahgre Valley	27,887	133,912	..	..	..	..	.93	1.02	.83	.92	.72	.39	..	..	4.81	140,601
Idaho, Boise (Upper)	45,664	77,514	..	..	.01	.02	.23	.58	.54	.16	.15	.01	..	..	1.70	360,149
(Lower)	19,378	45,130	..	..	..	.00	.32	.46	.78	.50	.21	.05	..	..	2.32	114,491
Minidoka	70,239	304,172	..	..	..	.12	.55	1.01	1.13	.81	.58	.13	..	..	4.33	508,994
Montana, Flathead	4,203	8,345	..	..	..	..	.03	.69	.95	.28	.03	..	..	..	1.98	17,599
Huntley	14,425	21,437	..	..	..	..	.06	.38	.36	.57	.12	..	..	..	1.49	46,994
Sun River	6,824	11,688	..	..	..	..	...	.80	.72	.18	.01	..	..	..	1.71	20,392
M.-N. D., Lr. Yellowstone	5,068	6,030	..	..	..	..	...	.08	.99	.09	.01	.02	..	..	1.19	15,404
Neb.-Wyo., No. Platte	50,250	113,251	..	..	..	..	.15	.75	.72	.23	.40	..	..	..	2.25	239,588
Nev., Truckee-Carson	25,050	62,707	..	..	.11	.39	.59	.61	.23	.21	.29	.05	..	..	2.50	243,913
N. Mex., Carlsbad	13,459	38,764	..	..	.12	.45	.44	.48	.44	.62	.18	.10	.05	..	2.88	85,086
Ore.-Cal., Klamath	23,834	26,929	..	..	..	..	.17	.29	.42	.21	.05	..	..	..	1.13	42,097
S. Dak., Belle Fourche	27,897	30,390	..	..	..	..	...	.68	.27	.03	.11	..	..	..	1.09	57,720
Wash., Okanogan	7,260	9,040	..	..	..	..	.10	.43	.43	.28	..	..	..	..	1.24	17,319
Yakima; Sunnyside Unit	62,800	192,983	..	..	..	.26	.52	.55	.59	.55	.34	.26	..	..	3.07	307,585
Tieton Unit	15,008	34,445	..	..	..	..	.40	.56	.51	.57	.23	..	..	..	2.27	47,675
Wyo., Shoshone	16,524	27,370	..	..	..	.00	.21	.58	.48	.27	.10	.01	..	..	1.65	50,100

Colo.-Uncompahgre Valley.—The apparently high percentage of water diverted which was delivered to the land was due to the fact that water was also supplied to the canals through additional feeder canals not measured. Area is for that directly under the U. S. R. S.

Idaho-Boise.—The upper system receives water directly from the main canal. The lower system receives water from the Deer Flat Reservoir. In the former system water was turned in February 5, in the latter system water was turned in April 12 and turned out October 22.

Idaho-Minidoka.—The water delivered to the land was measured at the heads of laterals.

Wash.-Yakima-Sunnyside Unit.—Losses in lateral system estimated at 15% of amounts measured at the headweirs, and this figure is used in estimating amount delivered to farms.

This table is intended to give a general idea of what may be expected under similar conditions elsewhere. The average applications may be considered as rather high for permanent conditions for the reason that many of these lands are new and require considerably more water than will be necessary ultimately. In general, it may be stated that more water was applied to the land than was absolutely necessary for growing the crops, so that in time, when the irrigators become more proficient and water becomes more scarce, the quantity applied to the land will no doubt be considerably reduced.

Distribution of Irrigation Water through the Season.—It is not sufficient to know the total quantity of water that is required in a season, but it must also be known how the use of this water is to be distributed through the season. This is necessary for determining the sufficiency of the water supply during the irrigation months, when storage is not provided, and also to determine the maximum capacity of canals. It is obvious that more water is required during the hot, dry summer months than earlier and later in the season. Fortunately, a general knowledge of the variation in the requirements for the different months is sufficient, as, if necessary, the quantities used can be adjusted in a considerable degree to the available supply. Generally speaking, the maximum requirement may be taken as 25 to 50 per cent greater than the average. The accompanying table is useful as furnishing general data on the distribution of water throughout the season. This table also gives the relation of the quantity delivered to the land to the quantity diverted into the main canal of the system. The difference does not represent the amount lost by seepage, as in most cases a considerable portion of the quantity diverted was wasted through wasteways and returned directly to the river. To obtain quantity lost by seepage, the quantities wasted must first be deducted from the diversion, and the remainder is then the sum of the quantities applied to the land, and the quantities lost by seepage. These sums, less the applied quantities given in the table, give the seepage losses in the entire system. These are shown in the following tabulation as far as the figures are available:

TABLE 11

Project	Total Canal Losses in Percent of Diversion, 1912	Project	Total Canal Losses in Percent of Diversion, 1912
Yuma.........	32	Carlsbad........	48
Orland........	20	Klamath........	36
Boise..........	37	Belle Fourche....	32
Minidoka......	27	Okanogan.......	47
Flathead.......	50	Sunnyside.......	27
Huntley.......	17	Tieton..........	17
Sun River......	26	Shoshone........	36
Lower Yel'stone.	43		—
North Platte...	21	Average.......	32%
Truckee-Carson.	34		

NOTE.—See Table 14, page 44, for seepage losses from canals in various materials.

It has often been assumed in investigations of irrigation projects, that one-third of the quantity diverted would be lost by seepage and evaporation in the canal system, and the above average seems to support this assumption. A detailed consideration of seepage losses for the purpose of designing canals is taken up later. A loss by seepage in the entire system of one-third the quantity diverted is considered to be sufficiently accurate for preliminary purposes.

Location of Point of Diversion.—The first examination will have indicated in a general way the elevation at which it is necessary to divert in order to cover a suitable body of land, and with this knowledge the stream must be examined for a suitable location for diversion works which will give the necessary elevation. In most cases it will be necessary to dam the stream, and it is then necessary to estimate the area of flooded lands in order to determine the amount of damages that will have to be paid to the owners for such flooding. For the present purposes, only a rough approximation of the flooded area is necessary, but ultimately careful calculations for determining the elevations of the backwater must be made. The bed and banks of the river should be examined for suitable foundations for dam and headworks, so that the general type of dam required can be determined. Cross-sections of the stream must be measured, and some topography (which can be taken at small expense) is helpful. The general type of dam and its length and height should be determined upon and an estimate of quantities prepared.

Location of Main Canal.—Having determined upon the location of a point of diversion, the location of the main canal may be started. (Not infrequently it happens that the point of diversion is dependent upon the location of the main canal, especially in rough country.) From the considerations already discussed, the size and grades of the canal, upon which depends its location, may be determined. The size and grades of the canal should, of course, be adjusted to the requirements of the land to be supplied, but a rough determination will suffice for preliminary purposes, and after the location has been surveyed and platted and a better knowledge is had of the areas to be irrigated the canal sections can readily be increased or reduced within certain limits without causing appreciable errors in the estimates.

Assuming that the irrigable lands are located in an elongated valley bordered by higher lands more distant from the stream, the main canal will follow along the highest points of the irrigable area, generally skirting along the foothills, following around the wider valleys of tributary watercourses, and jumping across the narrower ones. A preliminary location for the purpose of estimates requires the use of a transit and level, but great refinement is not necessary. Long shots may be taken with the level and the stadia may be used for measuring distances, only angle points being set and no curves run. In very rough locations it is necessary to set a large number of angle points if fair estimates are desired. After the fly-line, or a portion of it, has been run, the level party should go over the line and take elevations and transverse slopes at sufficiently frequent intervals to enable a profile to be drawn from which to estimate earthwork quantities, and structures such as flumes, pipes, etc.

Determination of Irrigable Area.—The main canal will generally be the upper boundary of the irrigable area, and the stream the lower boundary from which, after platting, the included area is measured. There must also be made surveys of the lands which are non-irrigable, or, in other words, not tillable, such as rocky land, swamp land, etc., and areas which are isolated, that is, too high to reach by gravity from the main canal. The boundaries of non-irrigable and isolated lands may be run by

transit and stadia. If the country has been subdivided into townships and sections, all surveys should be tied to land lines; otherwise it will be necessary to make surveys to tie all the above-mentioned surveys together. The areas of non-irrigable and isolated lands are measured and deducted from the total to get the net area irrigable, after which it may be advisable to modify the capacities and sizes of canal sections on which the canal location was based. These revisions may affect the estimates of quantities, but a relocation of the line for estimating purposes will not generally be required.

Reservoir Surveys.—These should be of sufficient accuracy to give the probable capacity of the reservoir within 10 to 20 per cent. If the reservoir is a natural lake, the survey should include an investigation of the possibility of storage by lowering the lake outlet by tunnel or trench excavation; the boundary of the lake should be meandered and profiles run up the slopes at frequent intervals to an elevation high enough to cover the highest elevation to which the water may be raised. The volume may then be found by measuring the areas at successive 5- or 10-foot contour intervals, and computing the volume between by the usual methods; if it is possible to lower the surface of the lake these profiles should be carried below the water surface by soundings. If the reservoir site is dry, a base line should be established, and the topography elaborated from the same by the use of the transit and stadia or plane table. From the topographic sheet the capacity is calculated as noted above. A topographic survey of the dam site should be made, together with sufficient test pits or borings to give a general indication of the nature of the foundations.

A scale of 400 feet to one inch, with 10-foot contour intervals, will ordinarily be found satisfactory for the reservoir site. For the dam site, a scale of 40 feet to one inch and contour intervals not greater than five feet should ordinarily be used. The best scales and contour intervals depend upon the local conditions, but those mentioned have given satisfactory results in many surveys for quite a wide range of conditions.

General Remarks on Canal Locations.—In making locations of canals the question of cost as affected by location is of prime

importance. In most systems the canal excavation constitutes by far the greater part of the construction cost of the project, and canal maintenance constitutes a very large portion of the maintenance costs. The first cost is often relatively less important than cost of operation and maintenance, and the locating engineer must keep both in mind. It is a comparatively simple matter to locate a canal so as to obtain the least quantity of earthwork, and this is susceptible of exact mathematical establishment, but maintenance and operating cost are not so easily calculated. No set rules can be formulated for proper locations to give minimum operation and maintenance costs. This must be left almost entirely to the experience and judgment of the locating engineer. The value of experience in this matter cannot be overestimated, and a knowledge of operation and maintenance of canals is necessary to obtain an economic location.

In locating a canal, effort should be made to keep the water section in cut as far as practicable, and high fills should be avoided as much as possible on large canals, as they are a source of endless danger and expense in operation and maintenance. One of the most important items to be kept in mind is that the water surface must be kept high enough to reach the adjacent land after an allowance has been made of sufficient drop to make a measurement of the water over a weir or other measuring device. This is especially true of the smaller distributaries from which the water is taken directly onto the land, and if neglected when the canal is constructed, the possibility of properly measuring the water may be irreparably lost, or the expense of rectifying the damage be very high, whereas the expense of making provision for a measurement when the canal was built would have added little to the cost. The proper drop in water surface to allow for making a measurement depends upon the quality of water to be measured, and the kind of device to be used for measuring, both of which should be definitely known before the location is made. It must also be remembered that it may be necessary to make these measurements when the canal is not operating at its maximum capacity, and unless means are provided for checking up the water to maximum elevation the measurement must be made

at a lower elevation. An adjustment must be made between the cost of raising the grade of the canal, providing checks for backing up the water, or cutting out a certain amount of land adjacent to the canal to provide the necessary drop when the canal is not running full.

CHAPTER III

DESIGN OF IRRIGATION STRUCTURES

To design irrigation structures properly requires a thorough knowledge of structural and hydraulic engineering. In addition to this, a knowledge of the special requirements of irrigation structures is necessary. Mechanical details of design are not here discussed, but the broad problems connected therewith are pointed out, and aids for their solution, in the form of tables and diagrams, are presented.

Storage Works.—The rapidly decreasing supply of unappropriated water from the natural flow of streams has in the past few years made the problem of storage works increasingly important. The problem is a very difficult one—perhaps the most difficult of all that the irrigation engineer encounters—and only brief mention can be made here of some of its principal features.

Naturally, the first point to be decided is the water supply available for storage. This has already been discussed, but an additional factor not previously considered is the probable evaporation from the reservoir. This is especially important in shallow reservoirs. The velocity of the wind and the total wind movement have a considerable influence on the evaporation. The evaporation is greater in humid than in arid regions and increases with the temperature. For these reasons a much greater allowance must be made for the evaporation from a reservoir located in a valley on the plains than from a reservoir in the mountains where the temperatures are lower, the atmosphere more humid, and the water surface more or less protected from the sweep of the winds. Experiments made in 1909–10 by the Weather Bureau, United States Department of Agriculture, gave the figures in Table 12 for the monthly and annual evaporation at various places, mostly in the Western States. The measurements were made in pans on the ground, floating in water, or elevated on stands. Calculations made by the experimenters indicate that the evaporation from a pan 2 feet in diameter is about 75 per cent, that from a pan 4 feet in diameter is about 50 per cent,

and that from a pan 6 feet in diameter is about 30 per cent greater than the evaporation from a large pond or lake. The figures in the table may be roughly corrected on this basis; thus,

TABLE 12

TOTAL AMOUNT OF EVAPORATION BY MONTHS

The figures contained in these tables have not been corrected for the wind effect, the temperature effect, the vapor-pressure effect, nor for the size of the pans, but they represent the observed evaporation at the pan as located. D is the diameter of pan in feet.

Number	1	2	3	4	5
Station	Salton Sea, 1,500 Ft. Inland	Salton Sea, 500 Ft. at Sea	Salton Sea, 7,500 Ft. at Sea	Indio, Cal.	Mecca, Cal.
Position of Pans	Ground $D=2$	$D=4$	$D=4$	Ground $D=6$	Ground $D=6$
January	5.08	3.61	3.41	3.18	2.92
February	7.42	5.01	5.09	5.08	5.00
March	12.50	6.75	6.95	7.50	8.07
April	15.75	9.00	8.75	12.05	10.87
May	19.00	11.00	10.50	15.84	12.72
June	21.50	13.50	13.00	16.11	14.23
July	22.15	14.77	14.03	16.34	15.21
August	18.50	12.53	12.19	13.78	13.22
September	15.50	12.40	12.08	12.37	10.29
October	13.19	9.20	9.24	8.91	10.29
November	7.49	6.21	5.96	5.17	4.13
December	6.42	4.67	5.25	3.00	2.98
Year	164.50	108.65	106.45	119.33	107.81

Number	6	7	8	9	
Station	Brawley, Cal.	Mammoth, Cal.	N. Yakima, Wash.	Hermiston, Oreg.	
Position of Pans	Ground $D=6$	Ground $D=6$	Ground $D=4$	Raft $D=4$	Ground $D=3$
January	3.05	4.24	1.75	1.25	1.50
February	5.00	5.67	2.50	1.25	1.75
March	8.00	8.99	6.25	3.00	4.25
April	10.74	12.02	7.91	7.28	9.28
May	13.79	15.52	8.36	7.89	11.38
June	13.68	16.75	8.90	9.54	13.84
July	14.14	18.00	10.74	12.04	17.48
August	11.26	13.73	9.41	11.07	16.89
September	10.15	12.16	5.51	7.35	10.09
October	6.99	9.49	3.15	3.88	6.08
November	4.09	5.26	2.00	2.00	3.00
December	2.66	3.70	1.50	1.50	1.75
Year	103.55	125.53	67.96	68.05	97.29

TABLE 12 (*Continued*)

TOTAL AMOUNT OF EVAPORATION BY MONTHS

Number	10		11	12	
Station	Granite Reef, Ariz. Salt River		California, O. Filtration Plant	Birmingham, Ala. East Lake Reservoir	
Position of Pans	Ground $D = 4$	Floating $D = 4$	Floating $D = 4$	Floating $D = 4$	Floating $D = 4$
January	4.59	4.25	1.00	1.50	1.50
February	4.75	4.40	1.50	1.50	1.50
March	6.25	5.25	2.50	2.25	2.25
April	9.00	7.00	4.12	4.45	5.36
May	11.50	9.50	5.07	5.91	6.36
June	13.50	12.00	6.21	7.28	7.54
July	14.25	12.75	7.20	7.36	6.96
August	14.23	12.50	7.26	7.34	7.32
September	13.76	11.00	5.63	6.00	5.59
October	11.31	8.31	3.00	4.00	4.00
November	7.39	6.56	1.50	2.25	2.25
December	4.65	4.22	1.00	1.50	1.50
Year	115.18	97.74	45.99	51.34	52.13

Number	13	14	15		16	17
Station	Dutch Flats, Nebr. Interstate Canal	Minidoka Dam, Idaho. Snake River 10 Feet Above Surface	Deer Flat, Idaho Boise Project		Lake Kachess, Wash., 10 Feet Above Surface	Ady, Klamath, Oreg.
Position of Pans	Ground $D = 4$	$D = 3$	Ground $D = 3$	Raft $D = 4$	$D = 3$	Floating $D = 4$
January	1.75	2.25	1.50	2.00	0.50	0.50
February	1.75	2.50	2.25	2.75	0.50	1.25
March	3.00	4.00	4.00	4.25	1.25	3.57
April	4.50	7.00	7.25	6.00	2.57	6.64
May	6.25	11.21	10.68	7.90	3.83	7.15
June	8.05	12.31	11.05	9.59	5.54	6.99
July	10.95	15.00	11.15	10.59	5.93	8.01
August	9.39	13.50	11.77	12.16	5.51	9.21
September	7.44	11.00	9.75	9.25	4.41	6.13
October	5.59	8.50	5.40	5.42	1.47	2.50
November	4.00	5.75	2.70	5.52	0.75	1.00
December	3.00	3.50	1.50	2.00	0.50	0.50
Year	65.67	96.52	79.00	77.43	32.76	53.45

TABLE 12 (*Concluded*)

TOTAL AMOUNT OF EVAPORATION BY MONTHS

Number	18	19	20	21	22	23
Station	Fallon, Nev.	Lake Tahoe, Cal.	Elephant Butte, N. Mex.	Carlsbad, N. Mex. At Reclamation Office	Alfalfa Field near Carlsbad	Lake Avalon, Pecos River
Position of Pans	Floating $D = 4$	2 Feet $D = 4$	Ground $D = 4$	Ground $D = 4$	Ground $D = 4$	Floating $D = 4$
January	1.75	1.75	2.50	5.00	5.00	4.50
February	1.75	1.75	2.75	5.50	5.25	4.50
March	2.25	1.75	4.50	8.94	8.95	5.51
April	3.25	2.00	8.00	11.68	11.09	7.45
May	5.25	3.00	11.50	12.86	10.95	10.12
June	7.86	4.25	13.45	12.40	9.06	11.05
July	9.86	6.19	11.57	12.00	10.58	12.88
August	8.70	7.08	10.48	11.03	9.32	12.00
September	5.13	6.22	8.58	9.76	7.84	9.50
October	3.35	3.60	6.76	7.58	5.88	7.00
November	2.50	2.62	3.86	5.50	5.43	5.75
December	2.00	2.00	3.00	5.00	5.00	4.50
Year	53.65	42.21	86.95	107.25	94.35	94.76

The true evaporation from a large pond or lake at Dutch Flats, Nebraska (No. 13), would be $65.67 \div 1.50 = 43.8$. The evaporation from a pan elevated 10 feet above the ground surface averages about 15 per cent greater than from the same size pan on the ground; thus, the true evaporation from a 3-foot pan at the ground surface at Lake Kachess, Wash. (No. 16), is $32.76 \div 1.15 = 28.5$ inches.

The seepage from the floor and sides of a reservoir may have a large influence on its storage capacity. The seepage is dependent upon the nature of the material composing its bottom and sides, and the location of the ground-water plane in the vicinity. The latter, together with the elevation of the water in the reservoir, will establish the grades on which the seepage water will flow from the reservoir. It follows, then, that these grades will produce a certain velocity of water through the material in the surrounding country, and consequently the porosity of this material may have a greater effect on the volume of seepage than the porosity of the material composing the bottom and sides of the reservoir.

Various types of storage dams are used, the most important being masonry, earth, rock-fill, and various combinations of these three. The best type for a particular location depends upon the nature of the foundations, profile of dam site, material available for dam construction, accessibility of site, etc. A site having good rock foundations and abutments is usually favorable for a masonry dam. If the cañon walls are steep and the cañon comparatively narrow, an arched masonry dam may be the best. Excavations have been dug from 50 to 100 feet deep to obtain suitable foundations for high masonry dams. Where a continuous solid rock foundation cannot be had, or where the cost of materials for a masonry dam would be prohibitive, a rock-fill or earth dam, or combination of the two, is adaptable.

Every storage dam across a stream having an unregulated flow must be provided with a spillway which should preferably discharge the water some distance downstream from the toe of the dam so as not to endanger the foundations of the dam and, in the case of earth dams, cause erosion by backwash. The records of flow of a stream do not usually include the maximum probable discharge, which is exceedingly difficult to predict. The maximum discharge that might occur must be assumed several times the maximum recorded, depending upon the length of time covered by the records. Fortunately, a reservoir will generally act as a regulator of the flow, and it will not usually be necessary for the spillway to discharge the water at the same rate that it comes into the reservoir. Table 13 gives the maximum rate of discharge of streams in the United States as determined by the Hydrographic Branch of the United States Geological Survey. A study of this table will give some idea of the probable maximum discharge from a given stream.

The location and design of outlet works vary with the type of dam. The outlet gates for a masonry dam are usually located on the upstream face or a short distance inside the face. Sometimes they are located in a tunnel running around the dam. The latter method is preferable where practicable. Earth and rock-fill and other dams having flat slopes require the construction of an outlet tower in which the operating gates are located, and

TABLE 13

MAXIMUM RATE OF DISCHARGE OF STREAMS IN THE UNITED STATES *

Stream and Place	Drainage Area, Sq. Miles	Date	Cu. Ft. per Sec. per Sq. Mile
Budlong Creek, Utica, N. Y.	1.13	1904	120.40
Sylvan Glen Creek, New Hartford, N. Y.	1.18	1904	56.58
Pequest River, Hunts Pond, N. J.	1.70	1904	25.30
Starch Factory Creek, New Hartford, N. Y.	3.40	1904	109.62
Starch Factory Creek, New Hartford, N. Y.	3.40	1905	209.00
Reels Creek, Deerfield, N. Y.	4.40	1904	48.36
Mad Brook, Sherburne, N. Y.	5.00	1905	262.00
Skinner Creek, Mannsville, N. Y.	6.40	1891	124.20
Coldspring Brook, Mass.	6.43	1886	48.40
Croton River, South Branch, N. Y.	7.80	1869	73.90
Woodhull Reservoir, Herkimer, N. Y.	9.40	1869	77.80
Mill Brook, Edmeston, N. Y.	9.40	1905	241.00
Stony Brook, Boston, Mass.	12.7	....	121.00
Great River, Westfield, Mass.	14.0	....	71.40†
Smartswood Lake, N. J.	16.0	....	68.00
Williamstown River, Williamstown, N. Y.	16.5	....	34.00
Croton River, West Branch, N. Y.	20.5	1874	54.40
Beaverdam Creek, Altmar, N. Y.	20.7	....	111.00
Trout Brook, Centerville, N. Y.	23.0	....	50.60
Wantuppa Lake, Fall River, Mass.	28.5	1875	72.00
Pequest River, Huntsville, N. J.	31.4	....	19.30
Sawkill, near mouth, N. J.	35.0	....	228.60
Whippany River, Whippany, N. J.	37.0	1903	61.62
Cuyadutta Creek, Johnstown, N. Y.	40.0	1896	72.40
West Canada Creek, Motts Dam, N. Y.	47.5	....	34.10
Six Mile Creek, Ithaca, N. Y.	47.5	1905	170.00
Sauquoit Creek, New York Mills, N. Y.	51.5	....	53.40
Rockaway River, Dover, N. J.	52.5	....	43.00
Oneida Creek, Kenwood, N. Y.	59.0	1890	41.20
Flat River, R. I.	61.0	1843	120.00
Camden Creek, Camden, N. Y.	61.4	1889	24.10
Nine Mile Creek, Stittville, N. Y.	62.6	1898	124.90
Wissahickon Creek, Philadelphia, Pa.	64.6	1898	43.50
Sandy Creek, Allendale, N. Y.	68.4	1891	87.70
Rock Creek, Washington, D. C.	77.5	....	126.30
Sudbury River, Farmington, Mass.	78.0	1897	41.38
Pequanock River, Pompton, N. J.	78.0	1902	55.78
Hockanum River, Conn.	79.0	....	78.10
Nashua River, Mass.	84.5	1850	71.04
Independence Creek, Crandall, N. Y.	93.2	1869	66.50
Passaic River, Chatham, N. J.	100	1903	17.20
Deer River, Deer River, N. Y.	101	1869	78.10
Wanaque River, N. J.	101	1882	66.00
Tohickon Creek, Mount Pleasant, Pa.	102	1885	112.50
Fish Creek, East Branch, Point Rocks, N. Y.	104	1897	80.50
Nashua River, Mass.	109	1848	104.53
Sandy Creek, North Branch, Adams, N. Y.	110	1897	67.30
Scantic River, North Branch, Conn.	118	....	51.80
Ramapo River, Mahawah, N. J.	118	1903	105.09

*From "American Civil Engineers' Pocket Book," John Wiley & Sons, New York.
†Average flow for day of maximum discharge.

TABLE 13 (*Continued*)

MAXIMUM RATE OF DISCHARGE OF STREAMS IN THE UNITED STATES

Stream and Place	Drainage Area, Sq. Miles	Date	Cu. Ft. per Sec. per Sq. Mile
Rockaway River, Boonton, N. J.	125	1902	22.24
Patuxent River, Laurel, Md.	137	1897	31.20
Meshaminy Creek, below forks, Pa.	139	1894	97.60
Oriskany Creek, Colemans, N. Y.	141	1888	55.80
Oriskany Creek, Oriskany, N. Y.	144	1904	29.00
Perkiomen Creek, Frederick, Pa.	152	1889	69.20
Mohawk River, Ridge Mills, N. Y.	153	....	46.40
Mohawk River, State dam, Rome, N. Y.	158	1904	27.34
Ramapo River, Pompton, N. J.	160	1882	56.10
Fish Creek, W. B., McConnellsville, N. Y.	187	1885	32.70
Unadilla River, New Berlin, N. Y.	204	1905	40.00
Salmon River, Altmar, N. Y.	221	....	27.60
Black River, Forestport, N. Y.	268	....	39.00
Croton River, Croton Dam, N. Y.	339	....	74.40
Great River, Westfield, Mass.	350	....	151.90
East Canada Creek, Dolgeville, N. Y.	356	1898	24.70
Moose River, Ayers Mill, N. Y.	407	....	31.00
Stony Creek, Johnstown, Pa.	428	....	70.00
West Canada Creek, Middleville, N. Y.	518	1898	24.90
Farmington River, Conn.	584	....	41.70
Monocacy River, Frederick, Md.	665	1898	29.80
Passaic River, Little Falls, N. J.	773	1882	24.20
North River, Port Republic, Va.	804	1896	29.80
Passaic River, Dundee, N. Y.	823	1903	43.38
North River, Glasgow, Va.	831	1896	44.80
Raritan River, Boundbrook, N. J.	879	1882	59.30
Potomac, North Branch, Cumberland, Md.	891	1897	22.80
Black River, Lyons Falls, N. Y.	897	1869	46.00
Schoharie Creek, Fort Hunter, N. Y.	948	1892	44.00
Genesee River, Mount Morris, N. Y.	1,070	{1894 1896}	39.20
Mohawk River, Little Falls, N. Y.	1,306	1902	21.83
Greenbrier River, Alderson, W. Va.	1,344	1897	41.60
Black River, Carthage, N. Y.	1,812	1869	21.20
Schuylkill River, Fairmount, Pa.	1,915	1898	12.20
Chemung River, Elmira, N. Y.	2,055	1889	67.10
James River, Buchanan, Va.	2,058	1896	15.60
Androscoggin River, Rumford, Me.	2,220	1869	25.00
Genesee River, Rochester, N. Y.	2,365	1865	17.00
Hudson River, Fort Edward, N. Y.	2,825	1900	15.60
Shenandoah River, Millville, W. Va.	2,995	1898	11.40
Mohawk River, Rexford, N. Y.	3,384	1892	23.10
Merrimac River, Lowell, Mass.	4,085	....	19.80
Kennebec River, Waterville, Me.	4,410	1896	25.20
Susquehanna, W. Branch, Williamsport, Pa.	4,500	....	11.60
Hudson River, Mechanicsville, N. Y.	4,500	1869	15.50
Merrimac River, Lawrence, Mass.	4,553	....	23.40
Potomac River, Dam No. 5, Md.	4,640	....	22.20
Delaware River, Lambertville, N. J.	6,500	....	53.80
Delaware River, N. J.	6,750	....	50.00
Delaware River, Stockton, N. J.	6,790	1841	37.59
Susquehanna River, Northumberland, Pa.	6,800	1889	17.50

TABLE 13

MAXIMUM RATE OF DISCHARGE OF STREAMS IN THE UNITED STATES *

Stream and Place	Drainage Area, Sq. Miles	Date	Cu. Ft. per Sec. per Sq. Mile
Budlong Creek, Utica, N. Y.	1.13	1904	120.40
Sylvan Glen Creek, New Hartford, N. Y.	1.18	1904	56.58
Pequest River, Hunts Pond, N. J.	1.70	1904	25.30
Starch Factory Creek, New Hartford, N. Y.	3.40	1904	109.62
Starch Factory Creek, New Hartford, N. Y.	3.40	1905	209.00
Reels Creek, Deerfield, N. Y.	4.40	1904	48.36
Mad Brook, Sherburne, N. Y.	5.00	1905	262.00
Skinner Creek, Mannsville, N. Y.	6.40	1891	124.20
Coldspring Brook, Mass.	6.43	1886	48.40
Croton River, South Branch, N. Y.	7.80	1869	73.90
Woodhull Reservoir, Herkimer, N. Y.	9.40	1869	77.80
Mill Brook, Edmeston, N. Y.	9.40	1905	241.00
Stony Brook, Boston, Mass.	12.7	....	121.00
Great River, Westfield, Mass.	14.0	....	71.40†
Smartswood Lake, N. J.	16.0	....	68.00
Williamstown River, Williamstown, N. Y.	16.5	....	34.00
Croton River, West Branch, N. Y.	20.5	1874	54.40
Beaverdam Creek, Altmar, N. Y.	20.7	....	111.00
Trout Brook, Centerville, N. Y.	23.0	....	50.60
Wantuppa Lake, Fall River, Mass.	28.5	1875	72.00
Pequest River, Huntsville, N. J.	31.4	....	19.30
Sawkill, near mouth, N. J.	35.0	....	228.60
Whippany River, Whippany, N. J.	37.0	1903	61.62
Cuyadutta Creek, Johnstown, N. Y.	40.0	1896	72.40
West Canada Creek, Motts Dam, N. Y.	47.5	....	34.10
Six Mile Creek, Ithaca, N. Y.	47.5	1905	170.00
Sauquoit Creek, New York Mills, N. Y.	51.5	....	53.40
Rockaway River, Dover, N. J.	52.5	....	43.00
Oneida Creek, Kenwood, N. Y.	59.0	1890	41.20
Flat River, R. I.	61.0	1843	120.00
Camden Creek, Camden, N. Y.	61.4	1889	24.10
Nine Mile Creek, Stittville, N. Y.	62.6	1898	124.90
Wissahickon Creek, Philadelphia, Pa.	64.6	1898	43.50
Sandy Creek, Allendale, N. Y.	68.4	1891	87.70
Rock Creek, Washington, D. C.	77.5	....	126.30
Sudbury River, Farmington, Mass.	78.0	1897	41.38
Pequanock River, Pompton, N. J.	78.0	1902	55.78
Hockanum River, Conn.	79.0	....	78.10
Nashua River, Mass.	84.5	1850	71.04
Independence Creek, Crandall, N. Y.	93.2	1869	66.50
Passaic River, Chatham, N. J.	100	1903	17.20
Deer River, Deer River, N. Y.	101	1869	78.10
Wanaque River, N. J.	101	1882	66.00
Tohickon Creek, Mount Pleasant, Pa.	102	1885	112.50
Fish Creek, East Branch, Point Rocks, N. Y.	104	1897	80.50
Nashua River, Mass.	109	1848	104.53
Sandy Creek, North Branch, Adams, N. Y.	110	1897	67.30
Scantic River, North Branch, Conn.	118	....	51.80
Ramapo River, Mahawah, N. J.	118	1903	105.09

* From "American Civil Engineers' Pocket Book," John Wiley & Sons, New York.
† Average flow for day of maximum discharge.

TABLE 13 (*Continued*)

MAXIMUM RATE OF DISCHARGE OF STREAMS IN THE UNITED STATES

Stream and Place	Drainage Area, Sq. Miles	Date	Cu. Ft. per Sec. per Sq. Mile
Rockaway River, Boonton, N. J.	125	1902	22.24
Patuxent River, Laurel, Md.	137	1897	31.20
Meshaminy Creek, below forks, Pa.	139	1894	97.60
Oriskany Creek, Colemans, N. Y.	141	1888	55.80
Oriskany Creek, Oriskany, N. Y.	144	1904	29.00
Perkiomen Creek, Frederick, Pa.	152	1889	69.20
Mohawk River, Ridge Mills, N. Y.	153	....	46.40
Mohawk River, State dam, Rome, N. Y.	158	1904	27.34
Ramapo River, Pompton, N. J.	160	1882	56.10
Fish Creek, W. B., McConnellsville, N. Y.	187	1885	32.70
Unadilla River, New Berlin, N. Y.	204	1905	40.00
Salmon River, Altmar, N. Y.	221	....	27.60
Black River, Forestport, N. Y.	268	....	39.00
Croton River, Croton Dam, N. Y.	339	....	74.40
Great River, Westfield, Mass.	350	....	151.90
East Canada Creek, Dolgeville, N. Y.	356	1898	24.70
Moose River, Ayers Mill, N. Y.	407	....	31.00
Stony Creek, Johnstown, Pa.	428	....	70.00
West Canada Creek, Middleville, N. Y.	518	1898	24.90
Farmington River, Conn.	584	....	41.70
Monocacy River, Frederick, Md.	665	1898	29.80
Passaic River, Little Falls, N. J.	773	1882	24.20
North River, Port Republic, Va.	804	1896	29.80
Passaic River, Dundee, N. Y.	823	1903	43.38
North River, Glasgow, Va.	831	1896	44.80
Raritan River, Boundbrook, N. J.	879	1882	59.30
Potomac, North Branch, Cumberland, Md.	891	1897	22.80
Black River, Lyons Falls, N. Y.	897	1869	46.00
Schoharie Creek, Fort Hunter, N. Y.	948	1892	44.00
Genesee River, Mount Morris, N. Y.	1,070	1894, 1896	39.20
Mohawk River, Little Falls, N. Y.	1,306	1902	21.83
Greenbrier River, Alderson, W. Va.	1,344	1897	41.60
Black River, Carthage, N. Y.	1,812	1869	21.20
Schuylkill River, Fairmount, Pa.	1,915	1898	12.20
Chemung River, Elmira, N. Y.	2,055	1889	67.10
James River, Buchanan, Va.	2,058	1896	15.60
Androscoggin River, Rumford, Me.	2,220	1869	25.00
Genesee River, Rochester, N. Y.	2,365	1865	17.00
Hudson River, Fort Edward, N. Y.	2,825	1900	15.60
Shenandoah River, Millville, W. Va.	2,995	1898	11.40
Mohawk River, Rexford, N. Y.	3,384	1892	23.10
Merrimac River, Lowell, Mass.	4,085	....	19.80
Kennebec River, Waterville, Me.	4,410	1896	25.20
Susquehanna, W. Branch, Williamsport, Pa.	4,500	....	11.60
Hudson River, Mechanicsville, N. Y.	4,500	1869	15.50
Merrimac River, Lawrence, Mass.	4,553	....	23.40
Potomac River, Dam No. 5, Md.	4,640	....	22.20
Delaware River, Lambertville, N. J.	6,500	....	53.80
Delaware River, N. J.	6,750	....	50.00
Delaware River, Stockton, N. J.	6,790	1841	37.59
Susquehanna River, Northumberland, Pa.	6,800	1889	17.50

TABLE 13 (*Continued*)

MAXIMUM RATE OF DISCHARGE OF STREAMS IN THE UNITED STATES

Stream and Place	Drainage Area, Sq. Miles	Date	Cu. Ft. per Sec. per Sq. Mile
Connecticut River, Holyoke, Mass	8,660	1854	21.10
Potomac River, Point of Rocks, Md	9,654	1897	19.40
Connecticut River, Hartford, Conn	10,234	....	20.30
Potomac River, Md	11,043	....	42.60
Potomac River, Great Falls, Md	11,427	1889	41.20
Potomac River, Chain Bridge, D. C	11,545	1893	17.20
Susquehanna River, Harrisburg, Pa	24,030	1894	18.90
Coosawattee River, Carters, Ga	532	1901	31.86
Etowah River, Canton, Ga	604	1895	31.50
Tuckasegee River, Bryson, N. C	662	1899	58.23
Little Tennessee River, Judson, N. C	675	1901	85.24
Broad River, Carlton, Ga	762	1902	38.22
Saluda River, Waterloo, S. C	1,056	1903	18.00
Catawba River, Catawba, N. C	1,535	1901	53.10
Chattahoochee River, Oakdale, Ga	1,560	1899	27.92
Ocmulgee River, Macon, Ga	2,425	1902	20.97
Yadkin River, Salisbury, N. C	3,399	1899	31.60
Tallapoosa River, Milstead, Ala	3,840	1901	18.23
Coosa River, Rome, Ga	4,001	1901	16.04
Broad River, Alston, S. C	4,609	1901	28.44
Black Warrior River, Tuscaloosa, Ala	4,900	1900	27.89
New River, Fayette, W. Va	6,200	1899	17.83
Coosa River, Riverside, Ala	6,850	1898	10.53
Savannah River, Augusta, Ga	7,294	1888	42.50*
Tennessee River, Chattanooga, Tenn	21,418	1896	20.80
Des Plaines River, Riverside, Ill	630	1892	9.05*
Verdigris River, Liberty, Kans	3,067	1904	16.43
Neosho River, Iola, Kans	3,670	1904	20.33
Grand River, Grand Rapids, Mich	4,900	1905	10.00
Smoky Hill River, Ellsworth, Kans	7,980	1903	1.43*
Kanawha River, Charleston, W. Va	8,900	1875	13.50
Blue River, Manhattan, Kans	9,490	1903	7.25*
Republican River, Junction, Kans	25,837	1903	1.80*
Mississippi River, St. Paul, Minn	36,085	1897	19.70
Kansas River, Lecompton, Kans	58,550	1903	3.98
Gallinas River, Las Vegas, N. Mex	90	1904	129.10
Mora River, La Cueva, N. Mex	159	1904	139.70
Rapid Creek, Rapid, S. Dak	320	1904	2.85
Salt Creek, at mouth, N. Mex	3,052	1904	4.10
Hondo River, reservoir, N. Mex	1,387	1904	4.56
Canadian River, Logan, N. Mex	11,440	1904	12.29 a
Canadian River, Taylor, N. Mex	2,832	1904	32.11 b
Canadian River, French, N. Mex	1,478	1904	105.56 c
Pecos River, Fort Sumner, N. Mex	6,191	1904	7.29
Pecos River, Roswell, N. Mex	14,840	1904	3.75
Redwater River, Belle Fourche, S. Dak	1,006	1904	8.00
Sapello River, Los Alamos, N. Mex	221	1904	36.7
Purgatory River, Trinidad, Colo	742	1904	61.2
Salt River, Roosevelt, Ariz	5,756	1893	36.0
Verde River, McDowell, Ariz	6,000	1893	24.05 d

*Average flow for day of maximum discharge.

a, Rate for 12 hours. b, Rate for 7 hours. c, Rate for 0.5 hour. d, Rate for 24 hours.

TABLE 13 (*Concluded*)

MAXIMUM RATE OF DISCHARGE OF STREAMS IN THE UNITED STATES

Stream and Place	Drainage Area, Sq. Miles	Date	Cu. Ft. per Sec. per Sq. Mile
Salt River, Ariz	12,000	1891	24.69
Gila River, Florence, Ariz	17,750	1891	7.50
Pecos River, Santa Rosa, N. Mex	2,649	1904	17.56
Mora River, Weber, N. Mex	422	1904	65.70
Rio Grande, Rio Grande, N. Mex	11,250	1904	2.75
Yuba River, Bowman Dam, Cal	19	....	31.6
Sweetwater River, Sweetwater Dam, Cal	186	1895	97.5
Tuolumne River, Lagrange, Cal	1,501	....	30.6
San Joaquin River, Hamptonville, Cal	1,637	1881	36.51†
King River, State Point, Cal	1,742	1901	25.22
Kern River, Rio Bravo, Cal	2,345	1897	2.3†
Sacramento River, Iron Cañon, Cal	9,295	1904	23.47†
Yuba River, Smartsville, Cal	1,220	1904	49.02†
Feather River, Oroville, Cal	3,350	1904	31.49†
Stony Creek, Fruto, Cal	760	1904	29.21†

† Mean for day when discharge was a maximum.

a discharge conduit running through or around the dam. In this case, also, the latter method is preferable where practicable.

The gates and conduits must be designed to pass the required quantity of water at low as well as high heads corresponding to the fluctuations in the elevation of the reservoir water. To avoid the necessity of operating the gates at very high heads they are sometimes located at several levels, the upper ones being used when the water is high and the lower ones when the water is low, the water from the higher levels either shooting directly through the dam, in the case of a masonry dam, or dropping down a shaft in the outlet tower and thence through the outlet conduit, in the case of other dams. For high heads, ordinary slide gates are not suitable on account of the difficulty of operation and destructive effect of vibrations due to high velocities. For this purpose, some form of balanced cylindrical or needle valve is necessary. The use of a single gate is seldom advisable, but there should be two gates in series at each outlet, so that one will be supplemented by the other, and in case of damage to either the other can be used for regulation. This arrangement is imperative where the gates are to be submerged, and consequently inaccessible, for long periods of time.

In all forms of gates and valves, air should have free access to the chamber on the downstream side of the gate to prevent the periodic formation and release of a partial vacuum, which is so destructive to gates. Where the partial vacuum can be maintained at all stages of flow it will have no more destructive effect than that due to the increased velocity produced, but this is not usually the case.

High velocities flowing smoothly have very little destructive effect on concrete (see page 47), but a smooth flow is seldom obtained in the outlet conduit of a reservoir. To protect the concrete, conduits are sometimes lined with cast iron or semi-steel, the latter being used on account of its hardness and consequent resistance to erosion.

Diversion Dams.—There are two general types of diversion dam: those on impervious foundation and those on more or less pervious foundations. These in turn may each be subdivided into fixed crest dams and movable dams. A movable crest is necessary where a fixed crest of the required height would cause the backwater to flood the country excessively during periods of high water, the movable crest being removed from the path of the water to allow the flood to pass. The minimum length of dam will generally be roughly fixed by the topographic conditions at the site, and the height to which the water must be raised is fixed by the elevation of the irrigable land which it is desired to reach. It is very desirable that a movable dam be avoided, if possible, as good dams of this kind are generally expensive to build, as well as to operate and maintain. After the maximum probable flood in the river has been estimated, high-water marks have been located, and the required elevation of diversion and length of dam preliminarily fixed, calculations must be made of the effect at high water of damming the river with a fixed crest dam to raise the water to the diversion elevation at low water. The water will obviously be raised higher, due to this artificial obstruction, than it flowed before, and this effect will extend upstream an indefinite distance. In the case of a rapidly flowing stream confined between high banks, backing up the water may do no damage to lands upstream, but in case the opposite conditions obtain, the effect of damming up the water even a small

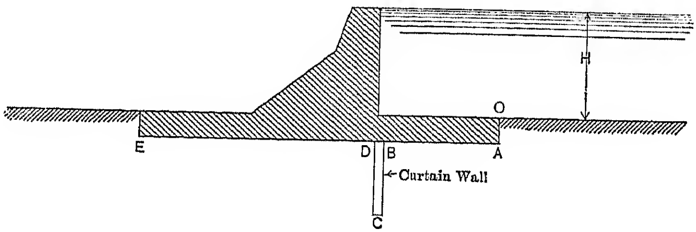
amount might prove disastrous. In the latter case there may be two solutions: the length of the dam may be increased or a movable crest may be used. It will generally be necessary to make many detail calculations before the proper adjustment is reached. The principal hydraulic calculations to be made in this connection are the determination of the depth of flow over the crest and the elevation of backwater at various points upstream. With the aid of Tables 28, 28 A, 28 B, and 28 C the depth of flow may be determined for various types of crest. If the determination of exact depth of flow is of great importance due to probable damage from backwater, it is well to select a type as close as possible to one for which definite coefficients are given.

Exact backwater elevations are very difficult to determine, as theoretical calculations fail almost entirely here. It is necessary that cross-sections of the stream be obtained at various points, and the slope of the stream, and, if possible, the value of "n" in Kutter's formula determined; if this can not be experimentally determined, it must be assumed. After the foregoing data are obtained, the loss of head, or drop in water surface, of the stream is calculated in successive short reaches by means of the formula $Q = A\,C\,\sqrt{RS}$. The total drop from any point upstream, calculated in this manner, added to the maximum elevation of the water surface at the dam gives the elevation of flood water at the point in question. This is a method of successive approximation, but may be depended upon to give more exact results than any backwater formula based on theoretical considerations only.

If a movable crest dam is used, the determination of depth of flow over the fixed crest need not be so exact, as a certain margin of safety can be applied in the height of the movable portion. For example: if the calculations show that a movable crest 5 feet high is required, then absolute safety may be assured by making this 5½ or 6 feet, and this will add relatively little to the expense.

Diversion dams located on pervious foundations—as many diversion dams are—must be designed to withstand a certain amount of upthrust, and it is usually assumed that this varies from the maximum hydraulic head at the heel to zero or a small

amount at the toe, or at such point as the water has egress from under the downstream apron of the dam. The unit upward pressure at any point is equal to the distance of that point from the heel of the dam divided by the total length of the path of percolation, multiplied by the depth of the water upstream. If there are cut-off or curtain walls, the path of percolation is assumed to follow around those walls. For example, the accompanying figure represents a dam subjected to a maximum head



of water above O equal to H. It is assumed that the pressure of the water percolating under the dam reduces to zero at E. $B\,C$ represents an impervious curtain wall, and the path of percolation is $O\,A\,B\,C\,D\,E$. The upward pressure at B, then, is equal to $\frac{H \times BCDE}{OABCDE}$; similarly the pressure at D is equal to $\frac{H \times DE}{OABCDE}$. It is obvious that the longer the apron $A\,B$ and the curtain wall $B\,C$ are made, the lighter may the cross-section of the dam be, and calculations should be made to determine what is the most economical arrangement. The upthrust pressures must, of course, be combined with the usual horizontal and vertical pressures of water and masonry to determine the tability of the dam.

Headgates.—In a stream that does not carry much silt, the headgates may be built perpendicular to the direction of flow of the stream, but in streams which do carry much silt, it will generally be necessary to build the headgates parallel, or nearly parallel, to the stream, and provide a sluicing channel through the dam in front of them in order to allow the periodic washing out of the channel; otherwise, large quantities of silt would

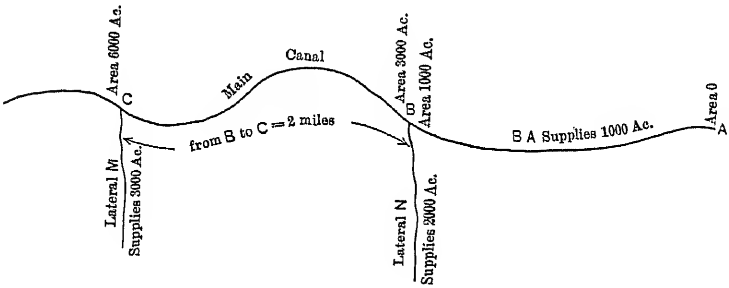
necessarily have to be carried into the canal. The velocity through headgates must generally be held to a comparatively low figure to avoid heavy washing in the canal or the necessity of expensive paving and other protective works for long distance downstream.

In some cases it is necessary to protect the gate openings with a grillage or screen to keep large floating débris from entering the canal. In other cases, a simple shear boom is sufficient, but this does not keep out material rolling along the bottom or carried in suspension. The kind and amount of protection depend entirely upon the nature of the stream and the location of the headworks relative to it. In streams in which fish abound, State laws sometimes require that a fish screen be placed in front of the gates to keep the fish from going down the canal. A satisfactory screen for this purpose has never been devised, the great difficulty being that in order to be effective in stopping the progress of the fish the mesh of the screen must be so small (from one-fourth to one-half inch) that the screen soon becomes clogged and interferes seriously with the regulation of water through the gates. The heavy expense of continually cleaning such a screen is obvious, and even then it is very difficult to keep a constant quantity of water flowing through the gates; the result is that the use of fish screens is not very popular.

Canals.—The determination of the most economical design for a canal is one of the most difficult problems with which the irrigation engineer has to deal, and there are many problems that must be considered. It is the purpose here to point out the most important of these problems and the methods of solution.

Capacity.—It is assumed that the engineer has before him a map showing the preliminary location of the main canal and the area to be irrigated. It is also assumed that it has been preliminarily determined at what points the principal laterals will divert from the main canal and the approximate areas they will irrigate. These points are marked on the map, together with the length of canal between them. The problem of capacity of canal at any point now involves the determination of the duty of water, or the amount required to be applied to the land, and

the determination of losses by seepage in the distribution laterals and main canal itself. The duty of water is discussed on page 20. For the purposes of main-canal design, the losses in the distri-



bution system may be taken as 15 per cent of the quantity diverted from the main canal.

In determining capacities it is convenient to begin at the lower end of the canal and work up, following through the same calculations for each successive reach. As an example: Suppose the accompanying figure represents the lower end of a canal; large laterals are to be taken out at points B and C. The duty of water (quantity applied to land) has been decided to be 2 acre-feet per acre per season; the irrigation season is 184 days long; the maximum capacity of canal required in mid-summer is 25 per cent greater than the average; the velocity to be used is 2.5 feet per second; the loss by seepage from the main canal is 1.5 feet in depth over the wetted area per day:

The duty of 2 acre-feet per acre in a season of 184 days corresponds to a flow of 1 c. f. s. to 182 acres. The lower reach of the main canal $B\ A$ is nothing more than a lateral, and it will be included with lateral N to give a total acreage just above B of 3,000 acres. At 1 c. f. s. to 182 acres applied to the land and with a loss by seepage in the laterals of 15 per cent of the diversions, the required maximum discharge of main canal at B is $\dfrac{3000 \times 1.25}{182 \times (1 - 0.15)} = 24.2$ c. f. s. If there were no seepage losses the capacity at C would be the same as at B as no laterals divert from the canal between these points. To determine the loss by seepage, assume the average flow in the reach $C\ B$ to

be 25 c. f. s.; enter the diagram, Fig. 3, with $Q = 25$ as an argument and find where this line intersects the inclined line marked $C = 1.5$, and read the seepage loss = 1.5 c. f. s. per mile on the scale to the left for $V = 1$ and for $V = 2.5$ follow the diagonal line to the left to its intersection with the vertical line marked $V = 2.5$ and read the seepage loss for the case in hand to be 0.95 c. f. s. per mile, or 1.9 c. f. s. for the two miles from C to B. The required capacity at C then is $24.2 + 1.9 = 26.1$ c. f. s. This process is now repeated for each successive reach above C until the head of the main canal is reached.

Seepage Losses.—For convenience, losses by seepage have frequently been expressed in terms of the percentage of water lost per mile, or other unit of length. This method is absolutely irrational and fortunately is rapidly falling into disuse, except for very general statements. The most rational and convenient means of stating these losses is in terms of the number of feet in depth over the wetted area of the canal prism lost in one day. The following formula* has been deduced for seepage loss:

$$S = 0.2\, C \frac{Q^{\frac{1}{2}}}{V^{\frac{1}{2}}}$$

Where S = loss in c. f. s. per mile of canal,
Q = discharge of canal in c. f. s.,
V = mean velocity of flow in feet per second,
C = the depth in feet over the wetted perimeter lost per day, and is found from observation on existing canals.

An exact expression for seepage loss involves the depth of flow, inclination of side slopes, and the ratio of depth to bottom width, but it is mathematically demonstrated in the article above referred to that the above formula which is based on side slopes of 1½ to 1 and a bottom width of four times the depth, gives results, for any shape or proportions of section, that are well within the limit of accuracy of the data which it is necessary to use in connection therewith.

Observations on several hundred miles of earth canals on

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* See *Engineering News*, Vol. LXX, page 402, for the derivation of this formula and a discussion of seepage losses.

eight different projects of the United States Reclamation Service give the following average figures for the value of C:

TABLE 14

SEEPAGE LOSSES FROM CANALS IN VARIOUS MATERIALS

Kind of Material	No. of Observations	Loss
Cement gravel and hardpan with sandy loam	3	0.34
Clay and clay loam	5	0.41
Sandy loam	4	0.66
Volcanic ash	3	0.68
Volcanic ash with some sand	5	0.98
Sand and volcanic ash or clay	8	1.20
Sandy soil with some rock	3	1.68
Sandy and gravelly soil	8	2.20

These are generally results from canals that have been in operation from three to six years. There is usually a very noticeable reduction in seepage losses with continued use, especially if the water carries fine silt, and there are instances where the most porous gravel formation has been made practically watertight by a coating of silt or puddle. In designing a canal, it is probably unsafe to figure on a smaller loss than 0.5 foot over the wetted area in 24 hours in even the most impervious material, and after a loss of over 2 to 2.5 feet is reached the question of lining the canals will generally require very serious consideration from the point of view of value of the water and damage to adjoining lands from waterlogging. The limits within which seepage losses should be considered may, therefore, be generally defined as 0.5 foot and 2.5 feet per day over the wetted area of canal, for the minimum and maximum respectively.

The manipulation of the equation is made very simple by the use of Fig. 3, which gives the loss by seepage in cubic feet per second per mile of canal for a large variety of conditions.

Side Slopes.—The proper slope to give the sides of a canal depends upon the stability of the material. Earth canals are generally given a slope of 1½ to 1 or 2 to 1, and these may be taken as the standard for ordinary conditions. When the channel is lined, the side slopes may be made of any inclination

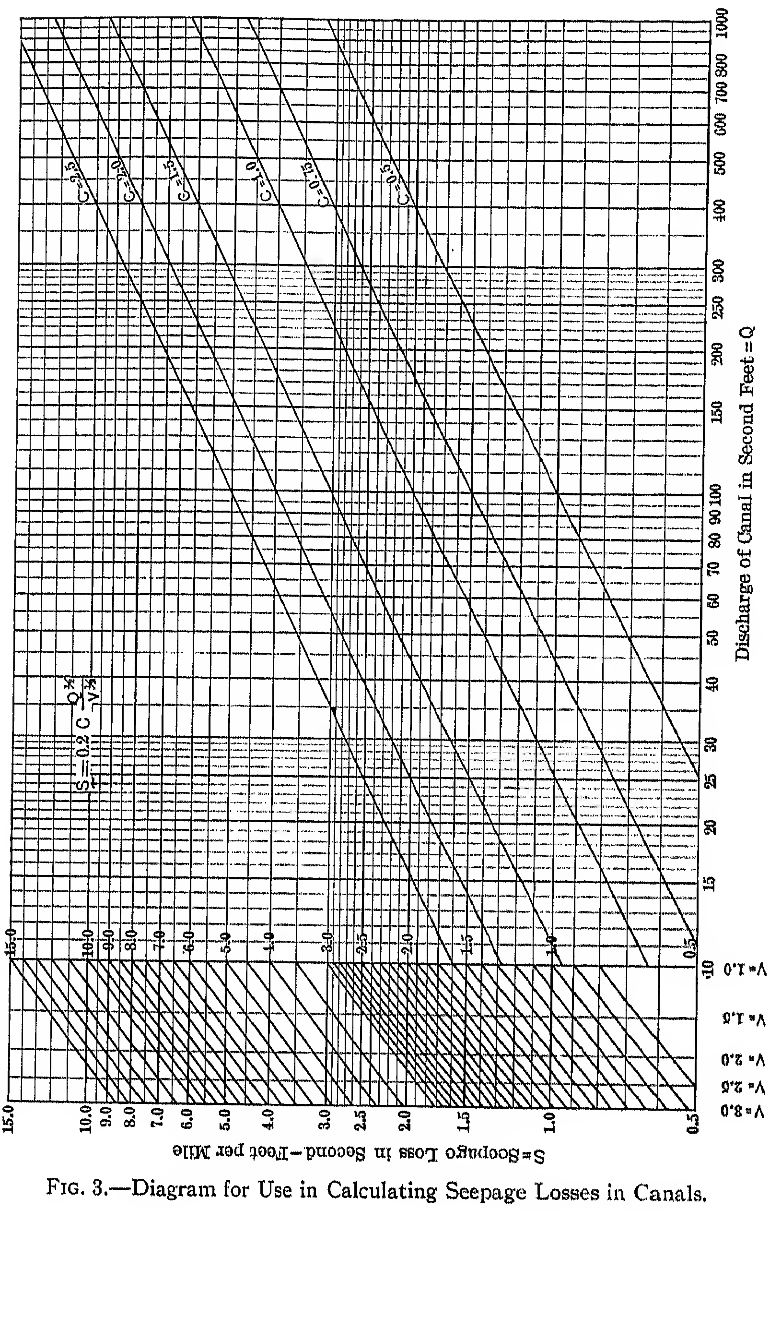


FIG. 3.—Diagram for Use in Calculating Seepage Losses in Canals.

up to vertical. On steep side-hill locations the slope on the hillside is often made steeper than the other slope in order to avoid excessive excavation. Usually no difference is made between the side slopes in cut and those in fill.

Depth of Flow and Bottom Width.—The depth and bottom width of a canal section are obviously interdependent. It has been stated that the maximum depth to use for an irrigation canal in earth should not exceed 8 feet, and for safety and economy in operation it is probable that the maximum line should be fixed at 10 feet, except for uncommonly large canals. It is very seldom that a canal is designed to have the best hydraulic elements, although it is a very easy matter to make such a design. One of the principal reasons for this is that the most efficient hydraulic section is too deep for its width, and such a section will not keep its shape, but tends to broaden and become more shallow. In rock and other hard material and for lined sections the most economical section can generally be used.

The best hydraulic section is the one that has the greatest hydraulic radius for a given area; such a section may be picked out by inspection from Figs. 14 to 21. For example: suppose the channel is to have 1 to 1 side slopes; the required area of cross-section is 200 square feet; what are the bottom width and depth that will give the best hydraulic section? Follow the line (Fig. 16 part 3) marked 200 at the bottom of the page to its intersection with the bottom width that gives the greatest hydraulic radius which we find to be about 9 feet; the corresponding depth is 10.3 feet; and the hydraulic radius is 5.23. In case of a rock or lined channel this section could be used, but for an earth section it would be too deep for its width.

The best ratio of bottom width to depth to use for a lined or rock section is usually fixed by considerations of economy only, but for canals in earth the depth should be limited, as before stated, to about 8 or 10 feet, although canals have been built with greater depths. Ratios of bottom width to depth from 2 to 1 to 6 to 1 are commonly used, depending largely on economy of construction and operation. Canals in materials which are easily eroded and broken down require the greatest relative bottom widths.

Velocities and Grades.—The velocities, and correspondingly the slopes, for concrete-lined sections are practically unlimited. Velocities as high as 90 feet per second have been used on concrete without destructive effect, but such velocities are not to be generally recommended. Velocities of 20 to 30 feet per second are common. Mr. A. P. Davis, in an article in *Engineering News* of January 4, 1912, sums up the results of investigations of the safe velocities on concrete as follows: "(1) That where clear water can be made to glide over concrete without disturbing its velocity or abruptly changing its direction, there is no practical limit to the velocities that can be permitted without harm. (2) That concrete which is subjected to the impact of water under high velocity is rapidly eroded, and that under such conditions the velocities must be very carefully limited." In rock sections, unlined, velocities of 10 to 12 feet are not often exceeded because the section is usually so rough that the loss of head with high velocities is very great; and also because many rocks will not stand a higher velocity continuously.

For canals in earth the velocity usually varies from 2 to 3 feet per second. Generally speaking, velocities less than 2 feet per second will allow the deposition of silt and over 3 feet per second will erode. There is probably not a canal in existence that does not deposit at some points and erode at others, even though the material be identical. The best velocity to use in a particular material is not subject to exact mathematical calculation. The mean velocity at which silt will deposit is said to be dependent upon the depth of the water, which is no doubt true. It is a well-known fact that small canals erode at a lower mean velocity than large canals. It is probably safe to say that the velocity in the largest canals in ordinary earth should not exceed 3.5 feet per second and in the smallest laterals 2 feet per second, and that the minimum velocities should be 2 feet and 1 foot, respectively. The result of too low a velocity is not only to deposit silt, but the growth of weeds and moss is encouraged, causing the channel to become foul and require frequent cleaning to maintain its capacity. Of the two evils it is better to build a canal with too high rather than too low a grade, as the former can be remedied without excessive expense

by the construction of checks, while the latter condition is generally impossible to correct except at prohibitive expense. In some canals, checks are necessary in order to back the water up to the high turnouts during times when the canal may be running at only about one-half or two-thirds its capacity. This requirement should, however, be avoided, if possible, by locating the turnouts low enough to take out their proportional quantity at any stage of the main canal flow.

From experiments made in India, Mr. R. S. Kennedy found that the velocity at which neither silting nor scouring of the canal bed will occur depends upon: (1) the depth of water in the canal, (2) the character of the silt, and (3) the quantity of silt carried in suspension. The experiments indicated that the critical velocity varied as the 0.64th power of the depth of canal, and the equation $Vs = 0.84\ D^{.64}$ was derived for water fully charged with fine, light sandy silt brought down by the floods of the rivers of northern India. For heavier materials the coefficient 0.84 is larger, and the general equation then is $Vs = m\ D^{.64}$. Values of m have been used from 0.84 to 1.09, as indicated in the accompanying table.

The equation $Vs = m\ D^{.64}$ is important to American engineers principally as indicating the probable variation of the scouring velocity with the depth of canal. It is generally agreed that a deep canal will stand a higher mean velocity than a shallower canal, but the above equation is probably the only attempt that has been made to express this phenomenon mathematically.

It is difficult to say how closely this equation fits American canals, but it is probable that the velocity, Vs, does not increase so rapidly with increasing depth. For canals carrying large quantities of silt the equation may give the true conditions with fair accuracy, but for canals carrying fairly clear water the exponent of D is probably smaller and is probably closer to 0.5 than 0.64. The critical velocity for canals carrying fairly clear water would then be $Vs = m\ D^{0.5}$. For convenience of comparison, a table has been calculated from this equation also, as it probably fits the conditions on American canals more closely than the other. It certainly agrees better with Ameri-

TABLE 15

CRITICAL VELOCITY, OR MEAN VELOCITY, AT WHICH A CANAL WILL NEITHER SILT NOR SCOUR

Based on Kennedy's formula $Vs = m\ D^{0.64}$

(*For silt-laden waters*)

Depth of Channel in Feet D	Fine, Light, Sandy Silt	Somewhat Coarser, Light, Sandy Silt	Sandy, Loamy Silt	Rather Coarse Silt or Débris of Hard Soils
	$m = 0.84$	$m = 0.92$	$m = 1.01$	$m = 1.09$
2	1.30	1.43	1.56	1.69
2.5	1.51	1.66	1.81	1.96
3	1.70	1.87	2.04	2.21
3.5	1.88	2.07	2.26	2.44
4	2.04	2.24	2.45	2.65
4.5	2.20	2.42	2.64	2.86
5	2.35	2.59	2.82	3.05
5.5	2.50	2.75	3.00	3.25
6	2.64	2.90	3.17	3.43
7	2.92	3.21	3.50	3.80
8	3.18	3.50	3.82	4.13
9	3.43	3.77	4.12	4.46
10	3.67	4.04	4.40	4.77
11	3.90	4.29	4.68	5.07
12	4.12	4.53	4.94	5.36

TABLE 16

CRITICAL VELOCITY, OR MEAN VELOCITY, AT WHICH A CANAL WILL NEITHER SILT NOR SCOUR

Based on formula $Vs = m\ D^{0.5}$

(*For canals carrying fairly clear water*)

Depth of Channel in Feet D	Fine, Light, Sandy Silt	Somewhat Coarser, Light, Sandy Silt	Sandy, Loamy Silt	Rather Coarse Silt or Débris of Hard Soils
	$m = 0.84$	$m = 0.92$	$m = 1.01$	$m = 1.09$
2	1.18	1.30	1.42	1.54
2.5	1.33	1.46	1.60	1.73
3	1.45	1.59	1.75	1.89
3.5	1.57	1.72	1.89	2.04
4	1.68	1.84	2.02	2.18
4.5	1.78	1.95	2.14	2.31
5	1.88	2.06	2.26	2.44
5.5	1.97	2.16	2.37	2.56
6	2.06	2.26	2.47	2.67
7	2.22	2.44	2.68	2.89
8	2.38	2.60	2.86	3.08
9	2.52	2.76	3.03	3.27
10	2.66	2.91	3.20	3.45
11	2.79	3.05	3.35	3.62
12	2.91	3.19	3.50	3.78

NOTE: This table is based on general hypotheses, and observation of American canals unsupported by experiments.

can practice. It should be remembered that this equation is not based on actual experiments, but on observation only.

Formula for Flow.—The tables and diagrams in this book for designing open channels are based on the Kutter formula:

$$V = \left\{ \frac{\dfrac{1.811}{n} + 41.6 + \dfrac{.00281}{s}}{1 + \left(41.6 + \dfrac{.00281}{s}\right)\dfrac{n}{\sqrt{R}}} \right\} \sqrt{RS}$$

in which V is the mean velocity in feet per second; R is the hydraulic mean radius; S is the " slope " or sine of the angle of inclination of the water surface; and n is an empirical coefficient varying with the roughness of the channel.

The formula was derived from experiments mainly on river channels, but it has been found fairly well adapted to the calculation of flow in all open channels, and the value of n has been determined for a large variety of conditions. For artificial channels the value lies between 0.010 and 0.035 for the smoothest and roughest respectively. The value for earth and rock sections, unlined, is generally considered to lie between 0.020 and 0.035, and for lined channels between 0.010 and 0.015. For well-built canals in earth in good order the value lies between 0.020 and 0.025, the lower figure being applicable to the more compact materials and the latter for lighter materials and those containing much coarse gravel. The value 0.0225 is very generally used for canals in earth. The value of n for rock sections depends very largely upon the amount of smoothing off that is done. With the amount of trimming that is generally done, the value probably lies between .030 and .035, while a carelessly excavated rock channel may have a value as high as 0.040, and a very smoothly trimmed channel may have as low a value as 0.025. If plenty of grade is available, it does not pay to smooth the channel up much, but if grade is valuable it may prove economical to do sufficient trimming to bring the value of n down to .025. The values .030 and .035 are in general use for rock sections.

For wood flumes or wood-lined channels a value of n of .012 is commonly employed, and experience seems to justify this

value. For concrete-lined channels $n = .013$ is in common use. Experiments seem to indicate that this value may be as low as .012 or even less for surfaces built against forms very smoothly finished with a steel trowel, while surfaces built without forms or with wood forms slightly uneven and not trowelled, the value is probably about .014. For any concrete surface reasonably well made, .015 is probably the upper limit, and considering the present state of our knowledge of the subject it is not safe to use a value less than 0.012.

Less is known in regard to the coefficients for steel flumes than for any other form of lining, but sufficient experiments have been made to indicate that the value is probably about .015 for rough joint flumes such as the Maginnis and about .012 for the smoother joint flumes, such as the Hess and Hinman. Some manufacturers claim values as low as .010 and .011 for their flumes, but there is not sufficient justification for the use of a value less than .012, especially since steel flumes have not been in use long enough to indicate what effect age may have on their carrying capacity. The accompanying tables * give the results of observations on concrete-lined and earth channels respectively, on projects of the United States Reclamation Service. These observations, although giving largely varying results, if carefully analyzed, indicate that the values .012 to .014, generally used for concrete channels, and .020 to .025, for earth channels, are justified. The great difficulty of measuring the slope and average velocity accurately explains sufficiently the large variations shown in the table, that are not explained by differences in the condition of the channel, and it is very unlikely that more uniform results can be obtained under practical conditions.

On account of the great uncertainties existing in the choice of a value of n, it is very desirable, especially for structures of great importance, to know what the hydraulic conditions would be if the value turned out to be something other than assumed. For example: A canal is under design in a material which it is known will probably erode excessively under mean velocities of 2.75 feet per second; the value of n is probably not less than

* Taken from the "Reclamation Record," published by the United States Reclamation Service.

TABLE 17

CONCRETE CHANNELS—VALUES OF KUTTER'S COEFFICIENT "n" FROM EXPERIMENTS

Ref. No.	Q	R	V	C	n	Length, Feet	Alignment	Condition of Surface, etc.
					UMATILLA PROJECT (Circular Section; 4.9 feet radius)			
1	205	2.13	7.10	129	.0132	640	Tangent.........	Concrete built with forms; not trowelled.
2	205	2.17	6.86	114	.0149	120	100 ft. Radius....	
3	205	2.15	6.94	90	.0189	220	50 ft. Radius....	
4	205	2.12	7.15	119	.0142	1075	Slight curve......	
					UMATILLA PROJECT (Trapezoidal Section; $1\frac{1}{4}$ to 1 side slopes; bottom width 1.5 feet)			
5	5.7	0.58	2.06	102	.013	932	Slight curve......	Smooth and regular.
					BOISE PROJECT (Trapezoidal Section; $1\frac{1}{2}$ to 1 side slopes; bottom width 40 feet)			
6	1011	4.89	3.34	135	.0142	1000	Tangent.........	Rough trowelled No. 6 had considerable rock and stone in bottom; others had small quantities of gravel and stone in bottom.
7	316	2.14	3.08	121	.0140	1000	"	
8	1027	3.88	4.68	121	.0154	1000	"	
9	476	2.64	3.57	115	.0152	1000	"	
10	245	1.95	2.64	111	.0149	1000	"	
11	119	1.44	1.84	91	.0170	1000	"	
12	1209	4.22	4.91	135	.0139	1000	"	
13	1011	4.33	3.90	116	.0164	2400	Number of short curves.........	Much gravel in bottom.
14	470	2.45	3.81	133	.0130	2400		Small quantity of gravel in bottom.
15	470	2.65	3.48	136	.0129	2400		
16	238	1.87	2.67	113	.0147	2400		
17	238	2.09	2.35	114	.0148	2400		Similar to No. 6 to No. 17. Concrete trowelled to smoother surface.
18	1027	3.64	5.00	148	.0124	2400		
19	456	2.89	2.98	145	.0123	2400		

TABLE 17 (*Concluded*)

CONCRETE CHANNELS—VALUES OF KUTTER'S COEFFICIENT "n" FROM EXPERIMENTS

				BOISE PROJECT (Trapezoidal Section; $1\frac{1}{2}$ to 1 side slopes; bottom width 10 feet)				
20	50	1.30	2.45	119	.0132	1000 to 2400	Numerous curves........	Very smoothly trowelled. Some gravel on bottom.
21	103	2.13	2.32	130	.0130		"	
22	230	2.73	3.35	145	.0122		"	
23	382	3.29	3.99	147	.0124		"	
24	50	1.30	2.43	123	.0127		"	Short selected sections nearly free from gravel. Very smoothly trowelled.
25	103	2.06	2.45	129	.0131		"	
26	230	2.72	3.37	158	.0112		"	
27	382	3.24	4.08	141	.0118		"	
28	376	3.11	4.32	142	.0126		"	Some gravel on bottom. Very smoothly trowelled.
29	318	2.90	4.15	138	.0129		"	
30	59	1.37	2.60	130	.0122		"	
				YAKIMA PROJECT, SUNNYSIDE UNIT (Circular Section, 4 feet radius)				
31	52.5	0.69	12.42	104	.0136	900	Short 2° curve....	Concrete built with wooden forms. No retouching of surfaces.
32	247	1.37	19.30	114	.0140	900	"	
33	242	1.36	19.13	114	.0140	900	"	
34	52.5	0.67	13.07	133	.0109	1300	Tangent.........	
35	247	1.33	20.44	148	.0110	1300	"	
36	242	1.30	20.62	150	.0108	1300	"	
37	45	0.62	12.52	132	.0109	1300	"	

TABLE 18

EARTH CANALS—VALUES OF KUTTER'S COEFFICIENT "n" FROM EXPERIMENTS

Note—Side slopes of all sections $1\frac{1}{2}$ to 1

Ref. No.	Q	R	V	C	n	Length feet	Condition of Surface, etc.
					NORTH PLATTE PROJECT		
1	1164	6.16	2.84	110	.0185	5280	Sandy; fair condition; erodes; some brush riprap.
2	1154	5.94	2.89	110	.0183	5280	"
3	1176	6.17	2.86	106	.0193	5280	"
4	1170	6.05	2.86	87	.0235	5280	"
5	1085	5.66	2.89	107	.0188	5280	Gravelly; good condition.
6	1075	5.82	2.81	128	.0158	5280	" "
7	1075	6.08	2.72	103	.0197	5280	" "
8	1075	6.18	2.59	99	.0207	5280	Gravelly to light; poor condition.
9	1075	6.36	2.47	76	.0274	5280	Light soil; bad condition.
10	1075	6.18	2.61	101	.0203	5280	Light and sandy; bad condition.
11	1137	5.79	2.92	108	.0187	5280	
12	1130	5.96	2.84	129	.0157	5280	
13	1130	6.21	2.77	100	.0204	5280	
14	1130	6.30	2.64	101	.0204	5280	
15	1130	6.46	2.53	75	.0280	5280	
16	1130	6.28	2.68	108	.0190	5280	
17	1057	5.58	3.13	110	.0181	5280	Gravelly; fair condition.
18	1056	5.64	2.87	103	.0194	5280	Sandy; fair condition.
19	1052	5.70	2.83	103	.0195	5280	Sandy; good condition.
20	1096	5.75	3.09	103	.0194	5280	
21	1094	5.81	2.84	101	.0199	5280	
22	1089	5.86	2.82	96	.0210	5280	
23	1194	6.01	2.94	124	.0164	10560	No. 11 and No. 12 combined.
24	1182	6.33	2.72	99	.0208	5280	Same as 13.
25	1180	6.23	2.75	104	.0197	5280	" 14.
26	1178	6.36	2.71	87	.0238	5280	" 15.

27	1176	6.55	2.69	117	.0178	5280	Same as 16.
28	1163	5.99	3.17	103	.0196	5280	
29	1161	6.02	3.03	97	.0209	5280	
30	1148	5.69	3.00	116	.0174	5280	
31	1140	5.78	2.97	125	.0160	5280	Same as 23.
32	1132	6.08	2.75	101	.0204	5280	" 24.
33	1130	6.10	2.75	112	.0183	5280	" 25.
34	1128	6.33	2.71	85	.0244	5280	" 26.
35	1126	6.44	2.69	114	.0181	5280	" 27.
36	1140	5.69	3.28	126	.0158	5280	
37	1132	5.58	3.32	114	.0175	5280	Same as 17.
38	1125	5.59	3.22	111	.0180	5280	" 19.
39	28.76	1.17	2.33	73	.0203	2000	
40	27.02	1.11	2.22	69	.0210	2000	
41	21.98	1.05	2.20	73	.0197	2000	Even numbers are on same reach.
42	21.94	1.03	2.09	70	.0204	2000	Odd numbers are on same reach.
43	9.98	0.75	1.68	67	.0199	2000	
44	10.27	0.73	1.71	66	.0201	2000	
45	20.04	1.02	2.13	71	.0201	2000	
46	20.09	0.97	2.08	70	.0203	2000	
47	13.56	0.82	2.09	91	.0155	2000	
48	11.57	0.73	2.21	82	.0166	2000	Even numbers are on same reach.
49	24.30	1.10	2.25	83	.0177	2000	Odd numbers are on same reach.
50	22.30	1.00	2.54	82	.0176	2000	
51	31.40	1.24	2.39	82	.0183	2000	
52	28.31	1.13	2.57	80	.0185	2000	
53	64.9	1.60	2.13	90	.0177	1600	
54	64.9	1.67	2.04	102	.0157	1400	
55	147	2.31	2.60	96	.0179	1600	
56	147	2.31	2.59	95	.0179	1400	Even numbers are on same reach.
57	148	2.32	2.57	99	.0172	1600	Odd numbers are on same reach.
58	148	2.33	2.50	90	.0188	1400	
59	167	2.40	2.62	99	.0172	1600	
60	167	2.39	2.61	92	.0187	1400	
61	173	2.41	2.67	98	.0175	1600	
62	173	2.41	2.67	93	.0185	1400	

TABLE 18 (*Continued*)

EARTH CANALS—VALUES OF KUTTER'S COEFFICIENT "n" FROM EXPERIMENTS

Note—Side slopes of all sections 1½ to 1

Ref. No.	Q	R	V	C	n	Length Feet	Condition of Surface, etc.
					NORTH PLATTE PROJECT		
63	49.9	1.42	2.02	83	.0187	1000	Observations 63 to 68 on same reach.
64	54.5	1.49	2.05	76	.0204	1000	
65	73.3	1.70	2.29	94	.0172	1000	
66	83.1	1.85	2.31	85	.0192	1000	
67	102	2.08	2.39	82	.0203	1000	
68	120	2.23	2.55	93	.0182	1000	
69	49.9	1.55	1.84	74	.0211	1000	
70	54.5	1.61	1.91	77	.0203	1000	
71	73.3	1.83	2.11	74	.0217	1000	
72	83.1	1.95	2.18	74	.0219	1000	
73	102	2.16	2.29	72	.0231	1000	
74	120	2.33	2.41	74	.0220	1000	
					TRUCKEE-CARSON PROJECT		
75	13.14	0.68	1.51	116	.013	100	Straight banks; bottom firm, smooth, slick.
76	13.93	0.84	1.33	100	.014	100	Coarse, sandy soil; banks good.
77	14.95	0.78	1.38	89	.0157	100	Coarse, sandy soil; banks good.
78	19.71	0.86	1.44	82	.0167	100	Some brush; bottom sandy in ridges.
79	18.08	1.16	1.27	80	.0181	100	Silted, firm, gravelly bottom; some weeds.
80	19.82	1.41	0.92	83	.0179	100	Slick mud over sand; no weeds.
81	20.18	0.87	1.41	77	.018	100	Bottom muddy and sandy.
82	23.60	1.13	1.10	75	.019	100	Straight, firm; coarse sand bottom.
83	20.00	1.06	1.22	75	.0202	100	Bottom sandy and ridged.
84	205.60	3.18	2.14	89	.0202	100	Sand and white clay.
85	150.06	2.63	1.48	83	.0201	100	Bottom firm and hard; banks loose.
86	20.16	1.63	1.24	75	.0208	100	Banks firm; bottom firm and sandy.

87	154.55	2.53	1.47	89	.0209	100	Banks loose; bottom firm and hard.
88	230.81	3.66	1.67	84	.0222	100	Firm, coarse gravel; large boulders on sides and bottom.
89	354.93	3.94	2.24	76	.0254	100	Hard soil; bottom washed.
90	135.18	2.06	1.55	63	.0259	100	Brush riprap on one side; bottom sandy.
91	50.68	1.60	1.51	59	.0260	100	Coarse, shifting sand on bottom; heavy grass on bank.
92	122.49	2.06	1.50	61	.0261	100	
93	139.58	2.16	1.59	64	.0277	100	Brush on both sides; sandy ridges on bottom.
94	423.05	3.77	2.12	69	.0280	100	Bottom sandy in ridges.
95	301.81	3.94	2.03	62	.0306	100	Firm, coarse sand; many large boulders.
96	314.01	4.19	2.10	55	.0346	100	½ concrete, ½ rock; very rough.
					BOISE PROJECT		
97	18.11	0.74	1.71	48	.0264	200 to 600	Bottom rather rough; hardpan gravel and sand; some weeds.
98	2.40	0.30	0.97	45	.0224		
99	7.42	0.68	1.23	48	.0260		Bottom hardpan and gravel; weeds hanging into water.
100	3.11	0.42	1.25	50	.0224		
101	4.26	0.52	1.16	52	.0225		Bottom sand and silt; no weeds.
102	1.79	0.34	1.04	42	.0244		Bottom hardpan, gravel, and mud; some weeds touching water.
103	3.50	0.44	0.87	36	.0293		Bottom rather rough hardpan.
104	2.10	0.56	0.44	44	.0251		Bottom smooth; muddy banks lined with weeds which hang into water.
105	58.24	2.07	1.18	57	.0286		Bottom sand and silt; banks overhang and are covered with grass.
106	46.21	1.60	1.60	61	.0254		Bottom rough; weeds on banks and in bottom.
107	1027.37	3.80	3.22	88	.0211		Clay and hardpan in good order; no weeds.
108	11.18	0.84	0.79	54	.0242		Black loam; some moss and weeds.
109	23.26	1.06	1.96	54	.0258		Sandy bottom; some weeds.
110	2.80	0.36	0.96	58	.0190		Very slick, black volcanic ash.
111	2.22	0.33	0.88	42	.0240		Fine-grained sand; no weeds.
					SALT RIVER PROJECT		
128	177	2.15	2.47	86	.0194	5000	Observations 128 to 145 made on same reach. Cross-sections uniform with fiber roots on side slopes holding silt deposits. Bottom was the original cement gravel with sprinkle of clean sand in pockets.
129	181	2.21	2.43	84	.0201	5000	
130	222	2.39	2.71	90	.0191	5000	
131	230	2.38	2.85	96	.0179	5000	
132	220	2.38	2.72	91	.0187	5000	

TABLE 18 (*Concluded*)

EARTH CANALS—VALUES OF KUTTER'S COEFFICIENT "n" FROM EXPERIMENTS

Note—Side slopes of all sections 1½ to 1

Ref. No.	Q	R	V	C	n	Length Feet	Condition of Surface, etc.
					SALT RIVER PROJECT		
133	230	2.39	2.74	83	.0190	5000	Observations 128 to 145 made on same reach. Cross-sections uniform with fiber roots on side slopes holding silt deposits. Bottom was the original cement gravel with sprinkle of clean sand in pockets.
134	220	2.39	2.62	79	.0200	5000	
135	230	2.40	2.65	86	.0198	5000	
136	220	2.40	2.53	82	.0207	5000	
137	176	2.06	2.48	89	.0186	5000	
138	167	2.06	2.36	85	.0194	5000	
139	176	2.07	2.57	91	.0186	5000	
140	167	2.07	2.44	87	.0193	5000	
141	176	2.07	2.56	90	.0179	5000	
142	167	2.07	2.52	89	.0188	5000	
143	141	1.87	2.32	87	.0190	5000	
144	146	1.92	2.33	86	.0193	5000	
145	500	3.75	3.06	82	.0229	5000	
150	151	1.98	1.95	70	.0230	5000	Observations 150 to 163 made on same reach. Side slopes were of silt with practically no vegetation. The bottom was covered to a depth of about one foot with clean, sharp sand, which under action of flowing water was formed into dunes about 0.8 foot high at right angles with the direction of flow. The dunes were about 8 feet apart and travelled with the current at the rate of about 2 or 3 feet per hour.
151	151	1.98	1.92	70	.0232	5000	
152	151	1.98	1.90	70	.0234	5000	
153	162	1.98	1.96	72	.0228	5000	
154	155	2.06	1.88	66	.0249	5000	
155	162	2.06	1.94	68	.0238	5000	
156	155	2.08	1.86	66	.0250	5000	
157	162	2.08	1.92	68	.0240	5000	
158	155	2.09	1.86	66	.0250	5000	
159	152	1.98	1.92	68	.0233	5000	
160	128	1.77	1.86	71	.0224	5000	
161	121	1.77	1.76	67	.0230	5000	
162	555	4.07	2.69	69	.0274	5000	
163	530	4.05	2.61	67	.0276	5000	

.020 nor more than .025. The canal is designed on the basis of mean velocity of 2.5 feet per second, and $n = .0225$, and the hydraulic radius is 4. If the value of n should actually be .020, instead of .0225, as assumed, what would be the resulting velocity? Fig. 33 gives a handy means of determining this (see explanation on page 82). We read from this diagram that the relative velocities for $n = .0225$ and .020 are as $\frac{0.51}{0.454}$ and the velocity with $n = 0.20$ would therefore be $2.5 \times \frac{0.51}{0.454} = 2.81$. This velocity is higher than is considered safe, and the designed velocity must, therefore, be reduced to 2.4 or less. In other cases it is desirable to know what effect a change in the value of n may have on the slope. This may also be ascertained from Fig. 33. A saving of a few feet in grade may be the means of reclaiming many additional acres of land, and a reduction of the value of n by lining the canal might bring this about. For example: We read from Fig. 33 that an unlined canal having a hydraulic radius of 5 feet and a value of n of .025 requires a slope of $\frac{6}{2.23} = 2.69$ times as great as the same canal lined so as to bring the value of n down to 0.15. This problem is most important in the smaller canals which require relatively steep slopes. Other problems present themselves in the solution of which this diagram is very useful. It is a requirement of good design to make calculations on the basis of various combinations of the hydraulic elements rather than on a single set of assumptions, as the latter may lead to disastrous results if the assumptions should prove to be erroneous.

Freeboard.—By freeboard is meant the vertical distance from the maximum flow water surface to the top of bank. The requirement for a certain amount of freeboard is obvious. This is not susceptible of mathematical calculation, and its value must be based on experience and accepted practice. For earth canals it is seldom made less than one foot for the smallest canals (not considering small laterals, for which the freeboard may be even less) nor greater than three to four feet for the

largest canals. These figures are for seasoned banks; when the banks are built, provision should be made for subsequent settlement and wearing down, due to travel on the banks, and in certain localities for wind erosion. For well-constructed banks an allowance of about 10 per cent should be sufficient for the former, while the latter is entirely dependent upon local conditions, but in most localities should not be an important item with properly maintained canals.

For lined canals the freeboard is usually made relatively considerably less and is dependent in some degree upon the velocity of flow. For higher velocities the freeboard is generally increased somewhat, especially at points where changes in grade occur, on account of the uncertainties existing in the calculations of depth of flow. Under high velocities the water surface fluctuates more and is more disturbed even under theoretically uniform flow, so that it is necessary to add a factor of safety in additional depth of freeboard. In general, it may be stated that the freeboard for lined canals with normal velocities should be about one-half that required for earth canals of corresponding size.

Where a lined canal having high velocities passes around a sharp curve the water piles up on the outside of the curve, due to its tendency to continue on the tangent. In such cases it is necessary to raise the lining on the outside above the normal freeboard, not only to allow for the piling up of the water but because of the greater disturbance of the water at this point. The amount the water rises on the outer side of the curve may be calculated approximately, and the value thus calculated should be increased 50 to 100 per cent to allow for the increased disturbance of the water surface. An approximate method of calculating the rise of water in passing around curves is as follows:

Consider any section made up of three plane surfaces, as in the figure on opposite page:

Let g = acceleration of gravity = 32.2 ft. per second, per second,

V = velocity of water in feet per second,

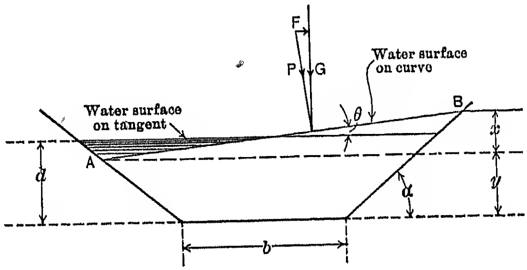
R = radius of curve in feet,

F = centrifugal force,
G = force of gravity.

Consider a unit of mass and the forces acting on it,

$$\text{then } F = \frac{V^2}{gR} \text{ and } G = 1.$$

Equilibrium will be established when there is no tangential force acting parallel to the surface A-B, which condition obtains



when the resultant P, of F and G, is perpendicular to A-B. We can then write the following equations:

$$P = G \div \cos\theta = F \div \sin\theta$$
$$\therefore F = G \tan\theta = \tan\theta$$
$$\tan\theta = \frac{x}{b + (2y + x)\cot\alpha} = \frac{V^2}{gR} \quad . \quad . \quad . \quad . \ (1)$$

Since the velocity of the water is the same on the curve as on tangent, or only very slightly smaller, the area of cross-section remains the same, and we then equate the two areas as follows:

$$by + y^2\cot\alpha + \frac{bx + 2xy\cot\alpha}{2} = bd + d^2\cot\alpha \quad . \ (2)$$

Simultaneous solution of equations (1) and (2) gives the values of x and y as follows:

from (1) $$x = \frac{V^2 b + 2yV^2\cot\alpha}{gR - V^2\cot\alpha}$$

substituting this value of x in equation (2)

$$by + y^2\cot\alpha + \frac{(b + 2y\cot\alpha)^2 V^2}{2(gR - V^2\cot\alpha)} = bd + d^2\cot\alpha$$

For simplicity let $2(gR - V^2\cot\alpha) = K$,

then

$$y = \frac{-(Kb + 4bV^2\cot\alpha) + \sqrt{(Kb + 4bV^2\cot\alpha)^2 - 4(K\cot\alpha + 4V^2\cot^2\alpha)(b^2V^2 - Kbd - Kd^2\cot\alpha)}}{2(K\cot\alpha + 4V^2\cot^2\alpha)}$$

The depth of water on outside of curve being equal to $x + y$, the height of lining must be increased an amount equal to $(x + y) - d$ in order to maintain the same freeboard as on tangents. To care for the greater disturbances of water surface on the curve, the additional freeboard should be $[(x + y) - d]$ multiplied by 1.5 to 2.

For vertical sides,

$$y = d - \tfrac{1}{2}x$$

and

$$x = \frac{V^2 b}{g R}.$$

Chutes.—Chutes, or inclined drops, are generally constructed of wood or concrete, the smaller structures as a rule being constructed of the former, while the larger structures are constructed of the latter. Open channels are preferable for this purpose because there is no danger of their becoming clogged up, but pipes are sometimes used. The latter should be protected at the intake by a suitable screen.

The design of an open chute is a process of successive approximation and is best explained by means of a concrete example:

Assume a canal of 500 second-feet capacity; the chute is 1,000 feet long and has a total drop of 20 feet, giving a slope of .02. The channel is to be of concrete with side slopes of 1 to 1; the probable value of n is .013. There are two cases to consider: one of variable slope and the other with uniform slope from intake to outlet. The processes to be followed in the two cases are similar, so that for simplicity of explanation the latter will be assumed. (Whether the slope is to be uniform or variable in a particular case depends upon the profile of the ground.) The velocity at the lower end of this steep channel will be much greater than at the upper end, and therefore the cross-section must be gradually contracted. The variation in cross-section is not uniform, and in order to approach approximately the theoretical cross-sections the total length is divided into a number of short reaches and the average cross-section calculated for each reach. The most rapid change in velocity and cross-section occurs at the beginning of the channel, and the lengths of reaches are made shorter here than is necessary further downstream, where the transition is more gradual. The accom-

panying table gives the results of the design of the channel in question, which was calculated with the assistance of Figs. 6, 16, and 34. The velocity at the intake was assumed as 2 feet per second. The velocity head at the intake is, therefore, 0.06 feet and the total head is the same. The total head at Sta. 0 + 50 is 0.06 + the drop of water surface in 50 feet = 1.06 feet. The design of the cross-section at the intake consists merely in determining bottom width and depth, which will give the required area, 500 ÷ 2 = 250 square feet. An infinite number of different sections will fulfil this requirement, but the one selected is $b = 30$ and $d = 6.8$. Before designing the section at Sta. 0 + 50, we note that the total available head is 1.06 feet. Since the average velocity in this reach must necessarily be comparatively low, the friction head will be small, and therefore most of this head will be available for accelerating the velocity. Hence, we assume that the probable velocity at Sta. 0 + 50 is about 8 feet per second, which corresponds to a velocity head of about 1.0 foot. By trying several velocities in the neighborhood of 8 feet we finally arrive at the quantities as shown in the table. The friction head, .02, is calculated by taking the velocity as the average of 2 and 8.2 or 5.1 and the hydraulic radius as the average of 5.08 and 2.32 = 3.7. The sum of friction head and velocity head must equal the total head, which criterion establishes the correctness of the section. Here also $b = 18$ and $d = 2.92$ is not the only combination which will fulfil the requirements; the bottom width might be increased and the depth decreased, or vice versa. The proper section to choose is a matter of judgment based on considerations of economy and simplicity of construction.

Station	Total Head	Velocity Head	Friction Head	R	V	Bottom Width	Depth
0	0.06	0.06	0	5.08	2.0	30	6.8
0+50	1.06	1.04	0.02	2.32	8.2	18	2.92
1+00	2.06	1.91	0.15	1.90	11.1	17	2.32
2+00	4.06	3.36	0.70	1.66	14.7	15	2.03
3+00	6.06	4.43	1.63	1.58	16.9	13	1.96
4+00	8.06	5.2	2.86	1.55	18.3	12	1.94
5+00	10.06	5.8	4.26	1.53	19.3	11	1.97
7+00	14.06	6.5	7.56	1.55	20.5	10	2.02
10+00	20.06	7.1	12.96	1.50	21.4	10	1.95

By a similar process each successive cross-section is designed, successive approximations of the velocities being made each time, and the friction head calculated from the average hydraulic radius and velocity between stations. This example was selected at random and is given as an illustration of the process only. It is not intended to represent a good design, although it might be considered satisfactory. Local conditions exercise an important influence on the choice of cross-sections, but whatever sections are decided upon, they must fulfil the hydraulic requirements as illustrated in the table. Great refinements are not necessary nor justified. As an illustration: If the bottom widths and depth shown in the table were satisfactory, it would be good engineering to make the first three depths 6.8, 2.9, and 2.3 respectively, and the remaining ones an even 2 feet.

A point sometimes lost sight of in designs of this kind is that it is the slope of the water surface and not the grade of the bottom of the channel that determines the velocity.

Sudden reductions in rate of grade should be avoided if possible, on account of the disturbances of the water surface that occur at such points. If sharp reductions of grade are unavoidable, the freeboard should be increased above the normal to provide for the disturbed conditions. In the case of pipe chutes, the conditions are reversed and sharp increases in grade should be avoided, and if possible the profile of the pipe should be kept concave upward. This is desirable on account of the tendency toward the formation of a vacuum at points where a sudden increase in grade occurs, and this tendency is most pronounced when the pipe is running on, or just below, the hydraulic gradient.

Flumes.—The design of flumes does not offer any special hydraulic problems. They are generally designed, and properly so, for a higher velocity than exists in the canal above, and it must be remembered that head to produce the increased velocity must be provided at the intake. For example, if the velocity in the canal is 2.5 feet per second, and that in the flume 6 feet per second, the extra drop to be provided at the head of the flume is $\frac{6^2 - 2.5^2}{2g} = 0.461$ foot. If the entrance is sharp an additional

allowance must be made for entry head. For a square entrance, that is, with headwalls of the intake perpendicular to the direction of flow, the entry head is generally taken as 0.5 of the velocity head, while for a gradual transition the loss may be as low as .05 of the velocity head. The velocity head in this case is that due to a 6-foot velocity, or .558 feet, and not the difference in velocity heads calculated above. If the above flume had a square intake, the total drop to be provided at the intake would then be $.461 + \frac{.558}{2} = .74$ ft. At the outlet of the flume a certain portion of the velocity head is recovered. The amount of this depends upon the construction of the outlet, and is difficult to estimate. The more gradual the transition the more head will be regained. It should not generally be estimated as more than 0.25 to 0.5 of the velocity head. The latter figure in the above case would give $0.461 \div 2 = 0.23$ feet on the assumption that the velocity in the canal below the flume is 2.5 feet per second.

For a rectangular flume, the greatest velocity for a given area obtains when the bottom width is twice the depth, as this proportion gives maximum hydraulic radius. For a circular cross-section, the maximum hydraulic radius obtains when the depth of water is about 1.6 times the radius, and is equal to about 0.61 R. The hydraulic radius is the same for a full circle as for a semicircle, being in each case equal to 0.5 times the radius.

The hydraulic elements of rectangular flumes are given in Fig. 14. For determining the discharge of small wood flumes, such as are generally used for irrigation laterals, Figs. 23 and 24 are very convenient. Fig. 29, in conjunction with Tables 23 and 24, gives the discharge of steel flumes of the standard sizes now manufactured. The value of Kutter's "n" for flumes is discussed under "Canals."

Pipe Lines.—In irrigation work, wood and concrete are the materials most frequently used for pipes, but steel is used for very high heads. Cast and wrought iron are seldom used on account of their high cost. Reinforced concrete pipes up to 46 inches in diameter have been built under heads as high as 110 feet, and it is probably not safe to use this type of construction,

in consideration of our present knowledge of the subject, for heads much greater than this. Wood pipes are ordinarily used for heads up to 200 feet, but may be used up to 400 feet. Steel pipes are specially adaptable for large pipes under heads greater than 200 feet. Occasionally two or more kinds of material are used in a single line.

The flow of water in pipes has been the subject of many researches. Most of these have dealt with cast-iron pipe, and the probable flow in these is better established than in pipes of any other material. Wood-stave pipes probably come next in order in the reliability of the calculations of carrying capacity, which is somewhat greater than that of cast-iron pipe. A considerable number of observations have been made on riveted steel pipe, but under such widely different conditions that it has been difficult to coordinate them. They indicate in a general way that the carrying capacity is about 10 per cent smaller than for cast-iron pipe. Very few experiments have been made on the carrying capacity of concrete pipe, and we are forced to resort to a comparison of the interior surfaces with those of cast-iron and wood pipe to arrive at an idea of its probable carrying capacity. Concrete pipe is built in various forms and by different methods. There is the dry-mix pipe, built in short (usually two-foot) sections, and laid and jointed in a similar manner to clay sewer pipe, and the wet-mix pipe, either built and laid in short sections as aforementioned, or built continuously in the trench. In the former case there is more or less roughness at the joints with possible jogs in the alignment, while in the latter the continuity is unbroken and better alignment may be obtained. The discharging ability of the continuous pipe with first-class workmanship may be as high as that of wood-stave pipe, while the wet-mix jointed pipe may better be classed with cast-iron pipes. However, in consideration of our meagre knowledge of the subject, the use of the cast-iron pipe formula is recommended for calculating the discharge of concrete pipe built continuously with steel forms, with a reduction of 5 to 10 per cent for jointed pipes, depending upon the amount of care used in producing a smooth interior surface. Dry-mix concrete pipe is adaptable only to very low heads and small diameters

on account of the impracticability of reinforcing it with steel. It has a considerably rougher surface than the wet-mix, and its carrying capacity under favorable circumstances is probably not greater than that of riveted steel pipe, and may be considerably less, if not very carefully laid.

Many formulas have been proposed for the flow of water in pipes, and it is difficult to decide which of these to use. Experiments seem to indicate that we cannot hope to get nearer than 5 to 10 per cent to the true values from any formula, and great refinements in the calculations of size of pipe are, therefore, not warranted. The United States Reclamation Service has adopted the following formulas * for calculating the carrying capacity of pipes:

Wood-stave pipe	$Q = 1.35\, D^{2.7}\, H^{.555}$
Cast-iron pipe	$Q = 1.31\, D^{2.7}\, H^{.555}$
Concrete pipe	$Q = 1.24\, D^{2.7}\, H^{.555}$
Riveted steel	$Q = 1.18\, D^{2.7}\, H^{.555}$

Q = Discharge in cubic feet per second.
D = Diameter of pipe in feet.
H = Friction loss in feet per 1,000 feet of pipe.

These formulas were derived from experiments on pipes of four inches and larger in diameter, and are, therefore, principally applicable for pipes of such sizes. Pipes smaller than 4 inches in diameter are seldom used for irrigation purposes. Fanning's formula is said to give accurate results for smaller pipes. The discharges of pipes 6 inches and smaller in diameter, calculated from Fanning's formula, are given in Table 19.

All of the above formulas cover friction losses only. Additional head must be allowed for bends, valves, etc. Allowance must be made at the intake for velocity and entry heads. The latter may be taken as 0.5 times the velocity head for a square intake, 0.25 for a rounded intake, and 0.05 for a bell mouth. Practically no data are available in regard to the loss of head in curves in large pipes. There can be no question but that the loss of head is greater on curves than on tangents, but as the

* See *Engineering Record*, vol. 68, p. 667, for a discussion of these formulas and a comparison of 17 different formulas for flow of water in pipes.

formulas are based on experiments which included the losses in curves in "friction" losses, ordinary curvature is probably safely provided for, and separate calculations for the curve losses are not necessary except when the alignment and profile are exceptionally crooked. No experimental data are available on the losses in long, sweeping curves, such as occur on irrigation and power lines.

TABLE 19

FLOW OF WATER, IN SECOND-FEET, IN SMOOTH, STRAIGHT IRON PIPES, FOR VARIOUS FRICTION HEADS, BASED ON FANNING'S COEFFICIENTS FOR FRICTION

Friction head, $H_f = 4f \frac{l\,v^2}{D\,2g}$ or $Q = 0.1\,D^2 \sqrt{\frac{DH}{f}}$

l = total length of pipe.
H = friction head in length l.
H = friction head per 1,000 feet of pipe.
D = diameter in feet.

Inside Diameter, in Inches	Friction Head, in Feet per 1,000 Feet of Pipe								
	1	2	3	4	5	6	7	8	9
1	0.0019	0.0027	0.0034	0.0040	0.0045	0.0050	0.0054	0.0058	0.0062
1½	.0055	.0079	.0099	.0116	.0131	.0145	.0158	.0170	.0181
2	.0124	.0178	.0220	.0256	.0288	.0318	.0345	.0370	.0394
2½	.0221	.0317	.0392	.0456	.0513	.0567	.0612	.0658	.0701
3	.0357	.0511	.0631	.0734	.0824	.0907	.0986	.106	.112
3½	.0533	.0765	.0942	.110	.123	.136	.147	.158	.168
4	.0752	.108	.133	.154	.174	.191	.207	.222	.237
5	.134	.191	.236	.275	.310	.340	.368	.396	.420
6	.214	.306	.378	.440	.495	.544	.591	.634	.675
	10	20	30	40	50	60	70	80	90
1	0.0066	0.0098	0.0124	0.0145	0.0165	0.0183	0.0198	0.0213	0.0227
1½	.0192	.0281	.0352	.0414	.0466	.0513	.0557	.0598	.0637
2	.0417	.0605	.0749	.0872	.0982	.108	.117	.126	.134
2½	.0740	.107	.132	.154	.173	.191	.207	.223	.238
3	.119	.171	.212	.247	.278	.306	.333	.357	.381
3½	.178	.256	.316	.369	.414	.456	.496	.532	.566
4	.250	.360	.446	.520	.585	.643	.698	.749	.797
5	.444	.639	.792	.924	1.04	1.14	1.24	1.33	1.42
6	.713	1.02	1.27	1.48	1.67	1.83	1.99	2.13	2.27

COEFFICIENTS OF FRICTION, f, FOR NEW PIPES IN FANNING'S FORMULA

Diameter	Velocity in Feet per Second			
	1	3	6	10
0.25 ft.	.0071	.0067	.0064	.0062
0.50 ft.	.007	.0063	.006	.0057

Figures 30, 31, and 32 show a plotting of the above formulas from which all the factors involved can be looked out at a glance. No separate diagram is given for concrete pipe, but the cast-iron or riveted steel pipe diagram, or an average of the two, may be used for this purpose, depending upon the type of construction to be used and the amount of attention to be given to producing a smooth interior surface.

The above formulas are for new .pipes. It is generally assumed that wood pipe increases in carrying capacity with continued use, but no reliance should be placed on this. It may, however, be safely assumed that a well-designed wood pipe will not decrease in carrying capacity with continued use. The effect of age on concrete pipe is not known, but it is customary to assume that the carrying capacity does not decrease, as there is no reason to suppose that it should. Cast-iron and steel pipes show a marked decrease in carrying capacity with continued use, and it is necessary that allowance be made for this. Williams and Hazen assume that the friction head increases 3 per cent per year, due to tuberculation, and that the diameter decreases 0.01 inch per year from the same cause. Applying these factors to the equation $Q = 1.31\ D^{2.7},\ H^{0.555}$, and letting K equal the ratio of discharge at the age of N years to discharge new, we get

$$K = \left(1 - \frac{N}{1200D}\right)^{2.7} \times \left[1 \div (1 + 0.03\,N)\right]^{0.555}$$

Thus from this equation we calculate that a 12-inch cast-iron pipe 10 years old will carry 85 per cent as much as the same pipe new, and at the age of 100 years it will carry only 36 per cent.

One of the most important features in the design of pipes to operate under pressure is to make provision for preventing the carriage of air through or accumulation of air in the pipe, as the presence of air in a pipe decreases the capacity in a marked degree. It is practically impossible to prevent the entrance of air at the intake, and for this reason it is always desirable to insert an air-relief pipe in the top of the pipe a short distance, say 15 or 20 feet, below the intake wall. The top of the relief pipe should, of course, be above the hydraulic gradient. Its

size depends upon the design of the intake, velocity of water, etc., but an area of one-twentieth that of the pressure pipe will generally suffice. In case of doubt the air relief should be made larger, as this can do no harm, or two pipes may be used, located from 5 to 10 feet apart.

Vertical Drops.—Drops are built in canals for the purpose of destroying excess grade, and their openings must be of such size that the maximum discharge of the canal will pass over them without raising the water upstream above the normal maximum elevation. The depth of water on the crest must, therefore, be calculated as for weirs and dams. Two types of drops are used, namely, those with rectangular openings, and the so-called "notched drops," which have the sides inclined so as to make the opening at the top wider than at the crest. The idea of the latter is to avoid a drop-down surface curve when less than the maximum discharge is flowing in the canal, which in the rectangular form must be accomplished by means of stop planks or other form of movable crest.

Below the weir of a drop a water cushion or depression below the bottom of the canal downstream is usually built. The purpose of this is to absorb the energy of the fall and to protect the floor from impact of the falling water. The proper depth of water cushion is a question to be determined by experience, which seems to indicate that a depth of one-third to one-half the height of fall is sufficient. For example: For a vertical drop of 6 feet between water surfaces above and below the weir, the floor below the weir should be depressed from 2 to 3 feet below the normal bottom of canal for a distance of two to four times the depth of water in the canal, the latter distance depending mainly on the quantity of flow. These figures are merely suggestions and must be used with discretion. It is impossible to absorb all the energy of the water in this chamber, and the canal below must be protected for some distance downstream by means of paving or some form of riprap. The amount of such protection cannot be ascertained in advance, and, moreover, this is not essential, as additional protection can be provided if necessary, after the canal is in operation.

Notched drops have been used in India to a considerable

extent, but have been used very little in the United States. The latter is probably due to the fact that coefficients of discharge for such openings are practically unknown, and because it is generally desirable on our canals to use the drop structure as a check as well, and for this purpose it must be adjustable. In this case there is nothing gained by using a notched drop, and rectangular openings with stop-plank control are, therefore. preferred.

Turnouts.—By a turnout is meant a structure for diverting water from a larger canal into a smaller. Turnouts for diverting large quantities are sometimes open sluices, but the great majority consist of a closed tube controlled by gates on the canal side. These tubes are nearly always so short that friction in the tube may be neglected, and provision need only be made for velocity and entry heads. The tube should be set low enough in the bank so that it can extract the required quantity of water with the minimum head in the main canal at which the turnout is to be operated. A general rule in a new system is to set the turnout tube so that it can extract its maximum required discharge when the canal from which it diverts is running at one-half to two-thirds of its maximum depth. For tubes built flush with the face of the headwall of the turnout, an allowance for entry head of 0.5 the velocity head is generally made. Turnouts are ordinarily designed for velocities of 3 to 5 feet per second. Comparatively low velocities are necessary, as a measuring device is usually placed just below the outlet of the tube and high velocities would vitiate the accuracy of measurements. Turnouts should not be operated under pressure on account of the danger to the bank in case leaks should develop. For this reason the location of regulating gates at or near the outlet of the tube is very ill advised.

Culverts.—Where canals cross drainage channels it is necessary to provide culverts for carrying the cross-drainage under the canal. These do not differ materially from culverts under highways and railroad grades, except that greater care must be exercised in their location and construction. They must be provided with cut-off walls on either side of the water section of the canal, and if possible the top of the culvert should be at

least two feet below the bottom of the canal to prevent excessive seepage of water from the canal along the outside of the culvert.

The principal hydraulic problem in connection with the design of culverts is the determination of the probable maximum discharge of the drainage channel. This is a vexatious problem at best, but it is most difficult in arid regions, where it is not uncommon for a channel to remain absolutely dry for a number of years, and then suddenly, due usually to a cloudburst, discharge many hundred second-feet. It is not advisable here, as in railroad culverts, to build first a temporary structure and replace this later by permanent construction after better data have accumulated in regard to the run-off, as the bed and banks should not be disturbed after they have once become seasoned, and wooden structures under large canals are dangerous. It is, therefore, necessary to make the construction permanent, and the opening must be built sufficiently large to carry the largest possible flood. The best method of determining the most probable maximum flood, in the absence of actual gagings, is to make measurements of the slope and cross-sections of the channel at high-water marks and calculate the discharge by means of Kutter's formula. High-water marks can usually be found at points where the channel is well defined. The value of n to be used in the calculations depends upon the nature of the channel. After calculating the discharge at various points, the maximum value found should be multiplied by 2 or 3, depending upon the probable reliability of the data. This is on the assumption that no measurements are available of the actual flow. Formulas based on the area of watershed are practically useless in arid regions, although cases occur where the use of such a formula offers the only available solution.

After the maximum discharge has been estimated, the opening is designed in a similar manner to turnout tubes. The openings are generally designed for a velocity of about 10 feet per second. Much higher velocities are not advisable on account of excessive eddying at the intake and washing of the channel below the outlet. The use of lower velocities may be necessary on account of lack of sufficient head, but this is unusual.

HYDRAULIC DIAGRAMS AND TABLES

CHAPTER IV

HYDRAULIC DIAGRAMS AND TABLES

Figs. 4 to 13 inclusive give slopes and velocities for varying values of hydraulic radius and for values of n from .010 to .035, the common range of practice. Kutter's formula is the basis of these diagrams, and the following suggestions are offered as an aid in the selection of the proper value of n:

n = .010 for straight and regular channels lined with matched planed boards; neat cement plaster; or glazed, coated, and enameled surfaces in perfect order. This value is seldom used in practice.

n = .012 for straight and regular channels lined with unplaned timber carefully laid; sand and cement plaster; or best and cleanest brickwork.

n = .013 for straight, regular channels, lined with concrete, having a steel trowelled surface in good order.

n = .014 for straight, regular channels lined with concrete, having a wooden trowelled surface in good order.

n = .015 for straight and regular channels of ordinary brickwork; smooth stonework; or foul and slightly tuberculated iron.

n = .020 for channels of fine gravel; rough set rubble; ruined masonry; or tuberculated iron; or for canals in earth, in good condition, lined with well-packed gravel, partly covered with sediment, and free from vegetation.

n = .0225 for canals in earth in fair condition lined with sediment and occasional patches of algæ, or composed of firm gravel without vegetation.

n = .025 for canals and rivers of tolerably uniform cross-section, slope and alignment in average condition, the water slopes being lined with sediment and minute algæ, or composed of loose, coarse gravel; also for very smooth rock sections.

n = .030 for canals and rivers in rather poor condition, having the bed partially covered with débris, or having compara-

tively smooth sides and bed, but the channel partially obstructed with grass, weeds, or aquatic plants; also for average rock sections.

n = .035 for canals and rivers in bad order and regimen, having the channel strewn with stones and detritus, or about one-third full of vegetation; also for rough rock sections.

Canals in earth with their channels half full of vegetation may have $n = .040$, and when two-thirds full of vegetation may have $n = .050$. In exceptional cases the value of n may reach .060.

It will be noted that the velocities in Figs. 4 to 8 for values of n up to .015 range from 2 to 35 feet per second. Channels in which these values of n are applicable are usually of such construction that velocities less than 2 feet are seldom used, and velocities over 35 feet per second are uncommon in any case. These limits have, therefore, been adopted in order to get as large a scale as possible. Similarly, in Figs. 9 to 13 inclusive, for values of n .020 to .035, the range of velocities is from 1 to 20 feet per second. These values of n apply especially to unlined channels in which velocities greater than 20 feet and less than 1 foot per second are very uncommon.

The scales of coordinates are all logarithmic, that is, instead of the actual distances or values measured in linear units being laid off on the vertical and horizontal axes, the logarithms of these values are laid off, just as is done on the ordinary slide rule. In fact, in the preparation of several of the diagrams in this book the scales were transferred directly from a 20-inch slide rule. Interpolations are made exactly as in linear scales, as the lines have been made sufficiently close together so that linear interpolation is sufficiently exact. The great advantage in the use of logarithmic scales is that a large range of values can be covered with the same degree of accuracy throughout, which is impossible on linear scales. As an illustration of the difference between the logarithmic and linear scales, refer to Fig. 4, and suppose that the values of R were plotted throughout on the same scale as that used from $R = .2$ to $R = .3$. The distance between the two is about one-half inch, that is, each half-inch represents a range of 0.1 in the value of R. If this scale were continued up to $R = 10$, we would have a diagram 49 inches high

instead of only 5 inches. A similar increase would occur in the horizontal scale if linear values of V were plotted. The linear scales would, of course, allow a more exact reading of the diagram for the higher values, but this is not necessary, nor even desirable, as the logarithmic diagram gives as high a degree of accuracy as is warranted by the formula and the data upon which its use is based. A further advantage of the logarithmic plotting is that the curves are straightened out and consequently easier to read.

The manner of using the diagrams, Figs. 4 to 13, is evident. Given any two of the three variables, the third is looked out from the diagram either directly or by ocular interpolation without any calculations. For the convenience of those who wish to know or make use of the value of c in the formula $V = C\sqrt{R\,S}$, these are given for the corresponding value of n. Table 21 gives a summary of these tables for all values of n.

Figs. 14 to 20 give the hydraulic elements of rectangular and trapezoidal channels. Each of these diagrams may be considered as being made up of two separate diagrams, the upper portion giving the relation between area, velocity, and discharge, and the lower giving the relation between the depth, area, bottom width, and hydraulic radius. All scales are logarithmic. The horizontal scale is identical for upper and lower portion, and forms the medium through which the two parts are connected. The manner of constructing the diagrams must be obvious, except, perhaps, the manner of plotting the hydraulic radius curves. These were plotted after the bottom widths had been plotted; the points were located on the bottom width lines by calculating the depths which, for the given bottom width, would give the required hydraulic radius; the locus of one set of such points forms a hydraulic radius curve.

To avoid an excessively large page and folded sheets, three pages are used for each type of channel. Each page, however, is a complete diagram for the range of values that it covers. The first page of each set is used for small channels, the second for medium-sized channels, and the third for large channels. For Figs. 19 and 20, only one page, that for large channels, is used, as there is seldom occasion to use mixed slopes on canals of

smaller size than those covered by this diagram. It should be noted that Fig. 19, which was computed on the basis of one side slope, $1\frac{1}{2}$ to 1, and the other 1 to 1, is applicable also to channels having both side slopes $1\frac{1}{4}$ to 1, the areas being exactly the same and the hydraulic radii only very slightly different. Similarly, Fig. 20 is applicable to channels having both side slopes $1\frac{3}{4}$ to 1.

In the upper portion of the diagrams, velocities up to 10 feet per second are covered, but velocities higher than this are frequently used; also, the entire width of the diagram, that is, the entire range of areas is covered by only one velocity, namely, 2 feet per second. The diagram is, however, arranged so that by mentally moving the decimal point any velocity can be used. As an illustration of this, refer to Fig. 15, Part 2, and assume that a channel has a bottom width of 18 feet, a depth of 4 feet, and a velocity of 5 feet per second. What is the discharge? In the lower part of the diagram, we find the intersection of the line representing a depth of 4 with the line representing a bottom width of 18; thence vertically to the line in the upper portion of the diagram representing a velocity of 0.5 (not 5) feet per second, and read the discharge 40 c. f. s. Now, since the velocity is 10 times that used in finding this quantity, the actual discharge is 400 c. f. s. instead of 40. This illustration represents a very simple case, but further inspection will show that the diagram can be used for any velocity by properly manipulating the decimal point. Further examples are worked out on the pages opposite the diagrams.

Fig. 21, consisting of two sheets, gives the hydraulic elements of circular segments for radii of 0.5 foot to 8 feet. The horizontal scale represents the depths of water and the vertical scale the corresponding areas. The hydraulic radii are shown in the same manner as for rectangular and trapezoidal channels in Figs. 14 to 20. For values of the radius R not covered in the diagram either directly or by interpolation, the table on page 146 opposite the diagram may be used.

Fig. 22 gives the discharge and velocity of circular conduits running full as calculated by Kutter's formula $n = .013$. By the use of the multipliers given on Part 1 of this diagram it can

also be used for values of n of .012, .014, and .015. These diagrams may be used for calculating the discharge of pipes when the Kutter formula is preferred for this purpose, but this formula is known to give erroneous results for pipes and Figs. 30, 31, and 32 are preferable for this purpose. The diagram is intended principally for calculating the flow in circular channels partly full by the use of Table 22 in connection with the diagram. The diagram gives the flow when the pipe is just full and the table gives the multipliers for discharge and velocity to reduce the same to the flow when the same pipe or circular conduit is flowing at any proportional depth. To illustrate the use of the diagram and table, several examples will be cited:

Problem: Find the discharge and velocity of a circular conduit 6 feet in diameter flowing at depth of .25 times the diameter on a slope of .003 or 3 feet per 1,000.

Solution: From Fig. 22 read the discharge 237 c. f. s. and velocity 8.4 feet per second. These figures are for the pipe flowing full. From the table find the multipliers for proportional depth of 0.25 and diameter of 6 feet to be .694 for the velocity and .136 for the discharge. The velocity and discharge for this pipe flowing 0.25 full on a slope of .003 then are:

$V = .694 \times 8.4 = 5.8$ feet per second,

and $Q = .136 \times 237 = 32.2$ c. f. s.

Problem: In the above pipe what would be the discharge and velocity if $n = .015$?

Solution: The table on Fig. 22, Part 1, gives the multiplier for $n = .015$ as .856. The discharge would, therefore, be $32.2 \times .856 = 27.5$, and the velocity would be $5.8 \times .856 = 5$.

Problem: 300 c. f. s. is to be carried in an 8-foot diameter conduit on a grade of .004, or 4 feet per 1,000 $n = .013$. How deep will it flow and at what velocity?

Solution: From Fig. 22 read the discharge of an 8-foot conduit flowing on a slope of 4 feet per 1,000 as 590 c. f. s.; the corresponding velocity being 11.7. The ratio of given discharge to "full" discharge is $\frac{300}{580} = .517$. Enter the table with this multiplier, and find that it corresponds to a depth of flow of

0.51 times the diameter. The multiplier of the velocity is observed to be between 1.008, 1.009, and the velocity, therefore, is $11.7 \times 1.0085 = 11.8$ feet per second.

Problem: In the above problem what would be the depth of flow and velocity for $n = .015$?

Solution: The discharge and velocity for $n = .013$ are read as before to be 590 and 11.7 respectively. The multiplier for $n = .015$ for a diameter of 8 feet is read from the table on Part 1 to be .859. The discharge and velocity for $n = .015$ are, therefore, $590 \times .859 = 506$ and $.859 \times 11.7 = 10$, respectively. The ratio of given discharge to full discharge is $\frac{300}{506} = .593$. Enter the table with this multiplier and find that it corresponds to a depth of flow of about .553 times the diameter. The multiplier for velocity is observed to be about 1.04, and the velocity, therefore, is 10.4.

Figs. 23 and 24 give discharges directly for various sizes of rectangular wooden flumes with different depths of water flowing therein. They cover the sizes commonly used on small sublaterals. Fig. 23 covers the smaller slopes, while Fig. 24 covers the steeper slopes, such as are commonly termed chutes. The discharges for three different depths of flow in the flume are given in each case, and interpolations may be made for other depths. The flumes are assumed to be constructed of lumber surfaced on one side and one edge, and are designated by their nominal dimensions. Thus, by an 8×8 flume is meant one made of 8-inch boards; the width being slightly less than 8 inches, due to the dressed edge. The side height is the width of an 8-inch *S* 1 *S* 1 *E* board less the thickness of the *S* 1 *S* 1 *E* bottom board. The diagrams may also be used for rough lumber with practical accuracy. The depth of side boards is always stated first, thus: An 8-inch $\times$ 12 inch flume has a width of slightly less than 12 inches and an outside depth of slightly less than 8 inches, the inside depth being equal to the width of the 8-inch *S* 1 *S* 1 *E* board less the thickness of the 12-inch *S* 1 *S* 1 *E* board, etc.

Fig. 25 is used for the design of small canals in earth. It is based on the assumption of side slopes $1\frac{1}{2}$ to 1, bottom width equal to twice the depth and a value of n of .0225. **Fig. 26**

gives similar data for a value of n of .025. These diagrams are to be used in conjunction with **Fig. 25½** for the complete design of a canal. Although these diagrams are based on the assumption that the bottom width is equal to twice the depth, they give results with sufficient accuracy between the limits of $b = d$ and $b = 3\,d$. Beyond these limits only approximate results are obtained. It is probably safe to say that a large majority of all earth canals of capacities up to 80 c. f. s. have side slopes of 1½ to 1, and are designed with a value of n of .0225 or .025. The usefulness of these diagrams is, therefore, plainly evident.

Figs. 27, 27½, and 28 are similar to the above, but cover on a larger scale canals of capacities up to 8 c. f. s. for which the larger diagrams are difficult to read.

Fig. 29 gives the discharge of semicircular steel flumes. The diagrams are based on a value of n of .012 and a freeboard (distance of water surface below top of flume) of one-sixth of the radius. If it is desired to use other values of n, or a different freeboard, the multipliers given in **Table 23** should be used. For example: the discharge of a 7-foot flume on a slope of .0008 is found from Fig. 29 to be 73.5 c. f. s.; this is for $n = .012$ and freeboard of one-sixth the radius, or 0.583 foot. If the value of n were .015 and the freeboard one-tenth the radius, or 0.35 foot, we would find under "$n = .015$" in the table the multiplier 0.788 to transfer to the new value of n, and under "Freeboard $1/10\ R$" we would find the multiplier for discharge 1.149 to transfer to this new value of the freeboard. The discharge for $n = .015$ and freeboard $= 1/10\ R$, or 0.35 foot, then, is $73.5 \times 0.788 \times 1.149 = 66.5$ c. f. s.

It is generally desired to know the corresponding velocity also. This is derived from the known discharge and area. The area of water section corresponding to different freeboards is given in the table. Thus, we find for the case in question, the area with freeboard of $1/10\ R$ is 16.8, and dividing this into the discharge 66.5 we get a velocity of 3.96 feet per second.

Table 23 gives the various elements corresponding to only four different depths of flow, viz: .417 D, .437 D, .45 D, and .458 D. This will ordinarily be sufficient for designing purposes, but it

is frequently desired to know the velocity and discharge for other depths, and these may be obtained by the use of **Table 24.** For example: Find the discharge and velocity for a 12 foot 1 inch flume flowing with a depth of 3 feet when the discharge of the same flume flowing at a depth of 0.417 D is given by the diagram as 300 c. f. s. and the velocity is given as 6.6 feet per second. A depth of 3 feet corresponds to .248 D. Enter the table under $D = 10$ feet, as the multipliers for larger diameters are practically the same, and find on the horizontal line marked .25 D the multiplier for velocity = .758, and the multiplier for discharge = .376. The correct values are somewhat less than this and are found by interpolation between .24 and .25 to be .754 and .370, respectively. The velocity in the 12 foot 1 inch flume flowing with the depth of 3 feet is, therefore, $.754 \times 6.6 = 5$ feet per second, and the corresponding discharge is $300 \times .370 = 111$ c. f. s. This table is also convenient when it is desired to obtain the depth of flow corresponding to a given discharge. Example: The discharge of a 10 foot 2 inch flume flowing with a freeboard of 1/6 R is 250 c. f. s.; at what depth will this flume flow when discharging 100 c. f. s.? The ratio of these quantities is $\frac{100}{250} =$ .400; in the last column of the table we see that a depth of .26 D gives the multiplier for discharge .407; the flume will, therefore, flow at a depth of slightly less than .26 D or 2.65 feet; also the multiplier for velocity is found to be slightly less than .776, and this multiplied by the velocity corresponding to a flow of 250 c. f. s. gives the velocity for a flow of 100 c. f. s.

Figs. 30, 31, and 32 give the discharge of wood stave, cast iron, riveted steel, and concrete pipes based on the formulas given on page 67.

Fig. 33 gives the relative velocities and slopes corresponding to different values of n. There are two sets of curves on the diagram, the one showing the variation of velocity and discharge (left scale) and the other the variation of the slope (right scale). The right and left scales give directly the comparison of other values of n with $n = .010$. For a comparison of any other two values of n it is necessary to read two figures from the diagram and obtain their quotient. For example: suppose it is desired

to know, other things being equal, what is the relative slope of a canal having a hydraulic radius of 2 for values of n of .02 and .025. For $n = .02$ the slope compared with $n = .01$ is 0.415 and for $n = .025$ the corresponding figure is 0.660. The ratio of the two or $0.66 \div 0.415 = 1.6$ shows that the slope for $n = .025$ must be 1.6 times as great as for $n = .020$. The relative discharges are similarly found to be 0.482 and 0.382, showing that the discharge for $n = .025$ is only $\frac{0.382}{0.482} = 0.8$ as great as for $n = .020$, other things being equal.

Fig. 34 shows the relation between head and velocity given by the equation $H = 1/C^2 \frac{V^2}{2g}$ or $V = C\sqrt{2gH}$. (The value of C as used here is the coefficient of discharge, although it is applied to the velocity.)

Fig. 35 gives the discharge of sharp-edged submerged orifices for various areas of opening calculated from the formula $Q = 0.61 A \sqrt{2 g H}$. This diagram is applicable to measuring orifices, and to small sluice openings when the multipliers given below the diagram are used. These multipliers are the average values obtained from a series of experiments made at the University of Wisconsin. The results obtained from the Wisconsin experiments are given in full in Table 20.

The forms of entrance and outlet used for the tubes in these experiments were as follows:

A. Entrance: all corners 90 degrees.
Outlet: tube projecting into water on down-stream side of bulkhead.

a. Entrance: contraction suppressed on bottom.
Outlet: tube projecting into water on down-stream side of bulkhead.

b. Entrance: contraction suppressed on bottom and one side.
Outlet: tube projecting into water on down-stream side of bulkhead.

c. Entrance: contraction suppressed on bottom and two sides.
Outlet: tube projecting into water on down-stream side of bulkhead.

c'. Entrance: contraction suppressed on bottom and two sides.

Outlet: square corners with bulkhead to sides of channel preventing the return current along the sides of the tube.

d. Entrance: contraction suppressed on bottom, two sides and top. Outlet: tube projecting into water on down-stream side of bulkhead.

TABLE 20

VALUE OF THE COEFFICIENT OF DISCHARGE FOR FLOW THROUGH HORIZONTAL SUBMERGED TUBE, 4 FEET SQUARE, FOR VARIOUS LENGTHS, LOSSES OF HEAD, AND FORMS OF ENTRANCE AND OUTLETS

Loss of Head, in Feet	Forms of Entrance and Outlet	Length of Tube, in Feet						
		0.31	0.62	1.25	2.50	5.00	10.0	14.0
		Value of the Coefficient of Discharge						
.05......	*A*	.631	.650	.672	.769	.807	.824	.838
	a	.762			.742	.810		.848
	b	.740			.769	.832		.862
	c	.834			.769	.875		.890
	c'							.875
	d	.948			.943	.940	.927	.931
.10......	*A*	.611	.631	.647	.718	.763	.780	.795
	a	.636			.698	.771		.801
	b	.685			.718	.791		.813
	c	.772			.718	.828		.841
	c'							.830
	d	.932			.911	.899	.892	.893
.15......	*A*	.609	.628	.644	.708	.758	.779	.794
	a	.630			.689	.767		.803
	b	.677			.708	.787		.814
	c	.765			.708	.828		.839
	c'							.829
	d	.936			.910	.899	.893	.894
.20......	*A*	.609	.630	.647	.711	.768	.794	.809
	a	.632			.694	.777		.819
	b	.678			.711	.796		.833
	c	.771			.711	.838		.856
	c'							.846
	d	.948			.923	.911	.906	.905
.25......	*A*	.610	.634	.652	.720	.782	.812	.828
	a	.634			.705	.790		
	b	.683			.720	.809		
	c	.779			.720	.854		
	c'							
	d	.965			.938	.928		
.30......	*A*	.614	.639	.660	.731	.796	.832	.850
	a	.639						
	b	.689						
	c	.788						
	c'							
	d	.984						

There have been no data of value published in regard to the coefficient of discharge of large sluice openings such as are used in canal headworks. In the absence of such data, a prediction may be made on the basis of the Wisconsin experiments, on the assumption that the sizes and shapes of openings used in practice have the same coefficients as the 4-foot square opening used in the experiments. It is a well-known fact that the shape of the opening has an influence on the coefficient of sharp-edged orifices, but to what extent this is true for openings such as are used in practice is not known. It is probable that the influence is smaller rather than larger in the latter case. On the whole, within the limits of variation in shape of any practical opening from the 4-foot square opening of the experiments, it is probably safe to assume that the difference in coefficients is slight, and, in any case, this must be accepted as the best assumption that can be made. By studying this table in connection with a particular design, the most probable value of coefficient of discharge can then be arrived at. It is a notable fact that the coefficient is increased by the addition of a short tube projecting into the down-stream water. This fact could well be taken advantage of in the design of headgates. The influence of the tube is most marked in the case of the fully contracted orifice, due to suction in the tube which tends to prevent the full contraction of the jet at the entrance. This also explains the difference in the effect of the tube for different degrees of contraction.

Figs. 36 and 37 give the discharge of sharp-edged Cippoletti and rectangular weirs, respectively. Experiments have shown that both the Cippoletti and the fully contracted rectangular weir give accurate results for heads up to one-third the crest length, but for higher heads the results are not accurate. The error has been found to vary from zero for $H/L = 1/3$, to 30 per cent for $H/L = 1$, or head equal to length of crest. These diagrams should, therefore, not be used for heads greater than one-third the length of crest. It should be observed that each diagram contains two sets of lines; the lower scale of discharges is applicable to the lower set, and the upper scale to the upper set. The scale of "Heads" is applicable to both sets of lines.

From Fig. 37 may be obtained the discharges for both suppressed and contracted rectangular weirs. The discharge of suppressed weirs is read directly. To obtain the discharge of a contracted weir, the discharge of a suppressed weir is read first, and from this is subtracted the value read from the line marked "Values of 0.666 $H^{5/2}$." In explanation of this: Francis formula for contracted weirs $Q = 3.33\ H^{3/2}\ (L - 0.2\ H)$ may be written $Q = 3.33\ L\ H^{3/2} - 0.666\ H^{5/2}$; the first part of this equation is the formula for suppressed weirs, and if the two parts of the equation are plotted independently, the difference between the values read from the two plotted lines gives the solution of the equation. Because the length "L" does not enter into the second part of the equation, only one line is necessary for all values of L.

Figs. 36 and 37 are applicable only to weirs having a free fall, and this should always be obtained if possible. In case it is absolutely necessary to make a measurement with weir submerged, the coefficients in **Table 25** may be used to obtain approximate results. This table is applicable to both diagrams. These diagrams make no allowance for velocity of approach. This should be reduced to a negligible quantity wherever possible, but if this cannot be done the coefficients in **Table 26** should be used.

Where a considerable velocity of approach exists the suppressed rectangular weir with Bazin's formula gives more exact results than are afforded by the Cippoletti or Francis formulas. The Bazin formula automatically corrects for velocity of approach by having inserted in the formula the height of weir crest above bottom of approach channel as one of the variables. The discharges per foot of length of weir calculated from his formula are given in **Table 28** for various heights of crest above approach channel. Prof. Richard R. Lyman has recently published some tables in a Bulletin of the University of Utah based on extensive experiments made at Cornell University and the University of Utah, which probably give the most accurate results for the range covered. These are given in **Table 27** and are useful where the greatest accuracy is desired.

Tables 28A, 28B, and 28C give multipliers to be used in

connection with Table 28 to obtain the discharge over broad-crested weirs such as are used for diversion dams.

Table 29 gives the number of acre-feet equivalent to a given number of second-feet flowing for a given length of time.

Fig. 38 is used for converting a given depth of water applied to land in a given number of days into terms of number of acres supplied by one second-foot. These are the two terms in which "duty of water" is usually expressed, and a simple means of transposing one into the other is very useful.

Table 30 contains a list of hydraulic formulas for convenient reference.

Suggestion:

$n = .010$ for straight and regular channels lined with matched planed boards; neat cement plaster; and glazed, coated, and enamelled surfaces in perfect order.

VALUES OF C IN THE FORMULA $V = C\sqrt{RS}$

R	Slope					
	.00005	.0001	.0002	.0004	.001	.01 and over
0.1	67	78	85	89	94	95
0.2	87	98	105	110	113	114
0.3	99	109	116	120	124	125
0.4	109	119	125	129	131	133
0.6	122	131	138	140	142	143
0.8	133	140	145	148	150	151
1.0	140	147	151	154	155	156
1.5	154	159	162	164	165	165
2.0	164	168	170	170	171	171
3.0	178	178	179	179	179	179
4.0	187	186	185	184	184	184
6.0	199	195	193	191	190	190
10	212	205	201	199	197	196
20	228	216	210	207	205	204

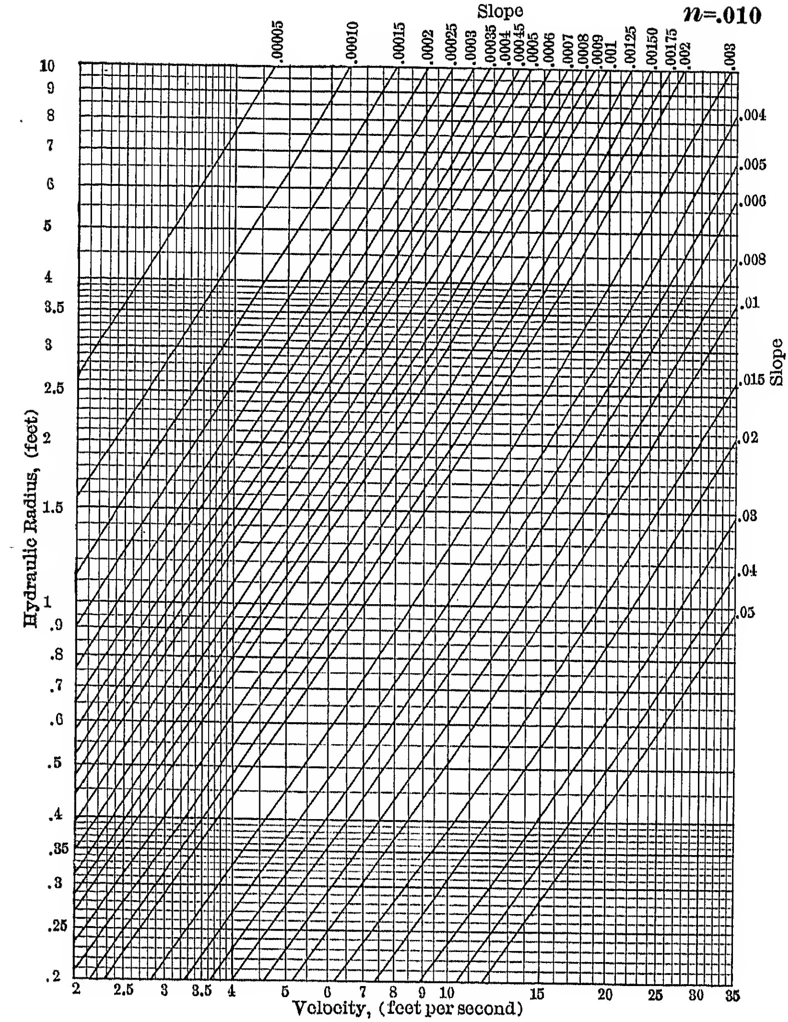

Slope
n=.010
.00005
.00010
.00015
.0002
.00025
.0003
.00035
.0004
.00045
.0005
.0006
.0007
.0008
.0009
.001
.00125
.00150
.00175
.002
.003
.004
.005
.006
.008
.01
.015
.02
.03
.04
.05
Slope
Hydraulic Radius, (feet)
10 9 8 7 6 5 4 3.5 3 2.5 2 1.5 1 .9 .8 .7 .6 .5 .4 .35 .3 .25 .2
2 2.5 3 3.5 4 5 6 7 8 9 10 15 20 25 30 35
Velocity, (feet per second)

FIG. 4.

Suggestion:

n = .012 for straight and regular channels lined with unplaned timber carefully laid, sand and cement plaster, best and cleanest brickwork, very smoothly finished concrete made with steel forms, and smooth-jointed galvanized steel flumes.

VALUES OF C IN THE FORMULA $V = C\sqrt{RS}$

R	Slope					
	.00005	.0001	.0002	.0004	.001	.01 and over
0.1	52	60	65	69	73	74
0.2	68	76	83	87	89	90
0.3	79	87	92	96	98	100
0.4	88	95	100	104	105	107
0.6	98	105	111	113	115	116
0.8	107	114	118	121	122	123
1.0	114	120	123	125	127	128
1.5	126	130	133	135	136	136
2.0	135	138	140	141	142	142
3.0	148	149	149	149	149	149
4.0	156	155	155	154	154	154
6.0	168	164	162	161	160	160
10.0	181	174	170	168	167	166
20.0	196	185	180	176	175	173

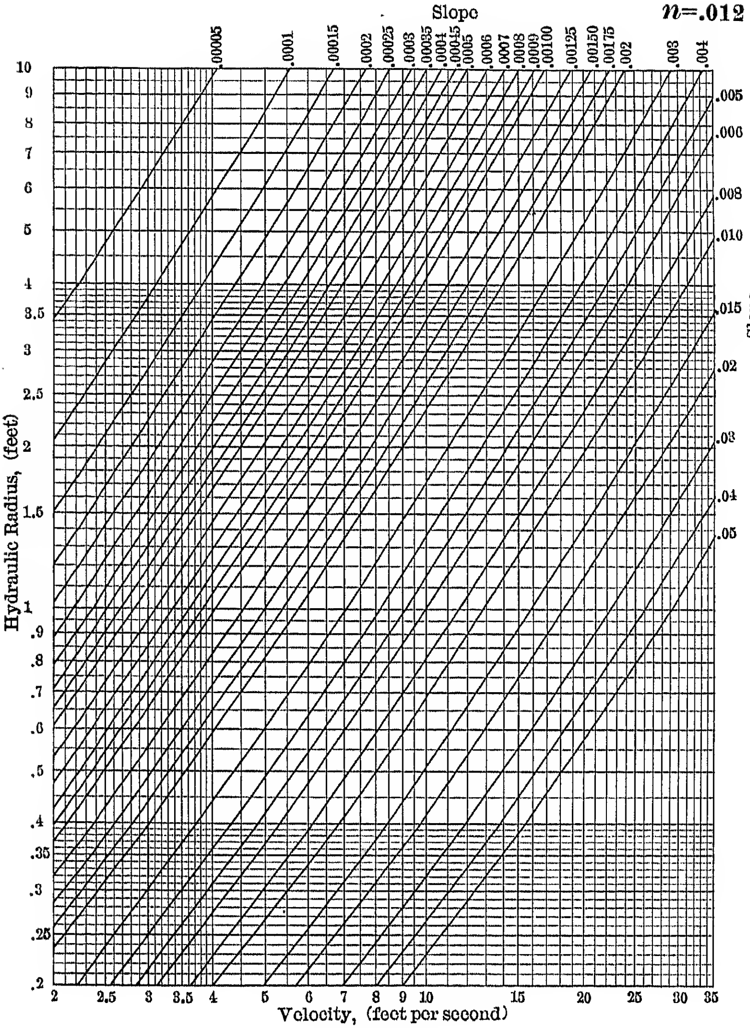

Slope
n=.012
.00005
.0001
.00015
.0002
.00025
.0003
.00035
.0004
.00045
.0005
.0006
.0007
.0008
.0009
.00100
.00125
.00150
.00175
.002
.003
.004
.005
.006
.008
.010
.015
.02
.03
.04
.05
Slope
Hydraulic Radius, (feet)
10
9
8
7
6
5
4
3.5
3
2.5
2
1.5
1
.9
.8
.7
.6
.5
.4
.35
.3
.25
.2
2
2.5
3
3.5
4
5
6
7
8
9
10
15
20
25
30
35
Velocity, (feet per second)

FIG. 5.

Suggestion:

$n = .013$ for straight regular channels, lined with concrete having a steel trowelled surface in good order.

VALUES OF C IN THE FORMULA $V = C\sqrt{RS}$

R	Slope					
	.00005	.0001	.0002	.0004	.001	.01 and over
0.1	47	54	59	62	65	66
0.2	62	69	74	78	81	81
0.3	71	78	83	87	89	90
0.4	79	86	91	94	96	98
0.6	90	96	100	103	104	106
0.8	98	103	107	110	111	112
1.0	104	109	113	115	116	117
1.5	116	120	122	124	124	125
2.0	124	127	129	130	130	130
3.0	136	137	137	138	138	138
4.0	145	143	143	142	142	142
6.0	156	152	150	149	149	148
10.0	169	162	158	157	155	154
20.0	184	173	168	164	163	161

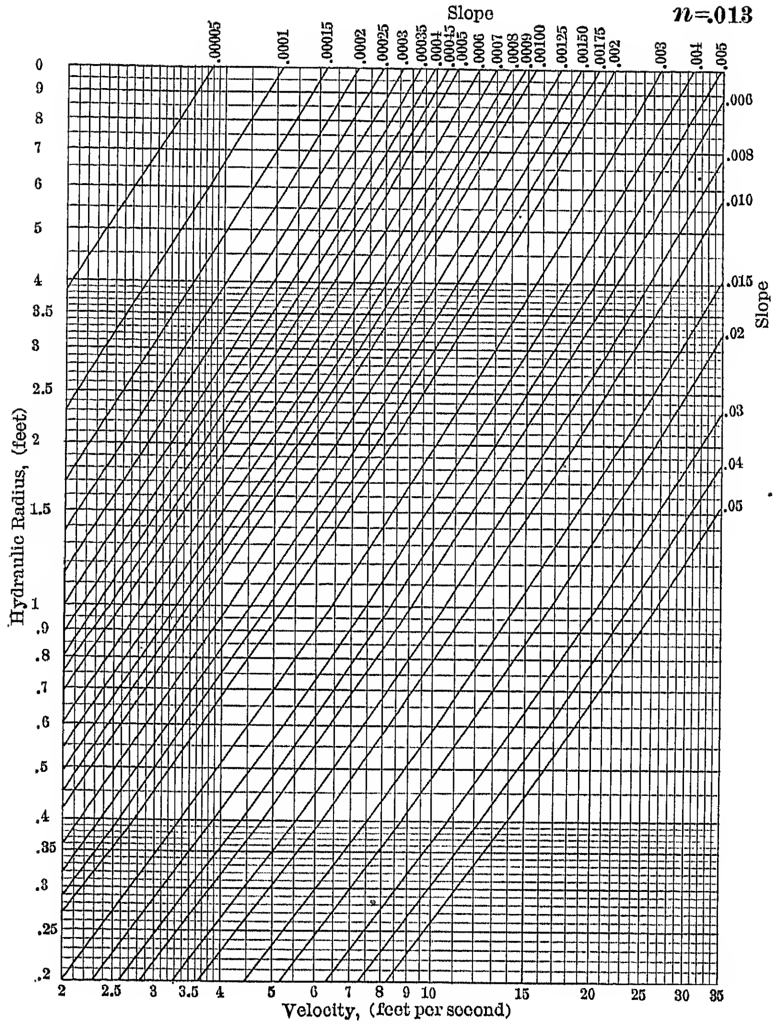

Slope
n=.013
.00005
.0001
.00015
.0002
.00025
.0003
.00035
.0004
.00045
.0005
.0006
.0007
.0008
.0009
.00100
.00125
.00150
.00175
.002
.003
.004
.005
.006
.008
.010
.015
.02
.03
.04
.05
Slope
Hydraulic Radius, (feet)
10 9 8 7 6 5 4 3.5 3 2.5 2 1.5 1 .9 .8 .7 .6 .5 .4 .35 .3 .25 .2
2 2.5 3 3.5 4 5 6 7 8 9 10 15 20 25 30 35
Velocity, (feet per second)

FIG. 6.

Suggestion:

n = .014 for straight regular channels, lined with concrete, having a wooden trowelled surface in good order.

VALUES OF C IN THE FORMULA $V = C\sqrt{RS}$

R	Slope					
	.00005	.0001	.0002	.0004	.001	.01 and over
0.1	43	49	53	56	59	60
0.2	56	63	67	71	73	74
0.3	65	72	76	79	81	83
0.4	72	79	83	86	88	89
0.6	82	88	92	95	96	98
0.8	90	95	99	101	102	103
1.0	96	101	104	106	107	108
1.5	107	111	113	114	115	116
2.0	115	118	119	120	121	121
3.0	127	127	128	128	128	128
4.0	135	134	133	133	133	132
6.0	146	142	140	139	139	138
10.0	158	152	148	146	145	145
20.0	174	163	158	154	153	152

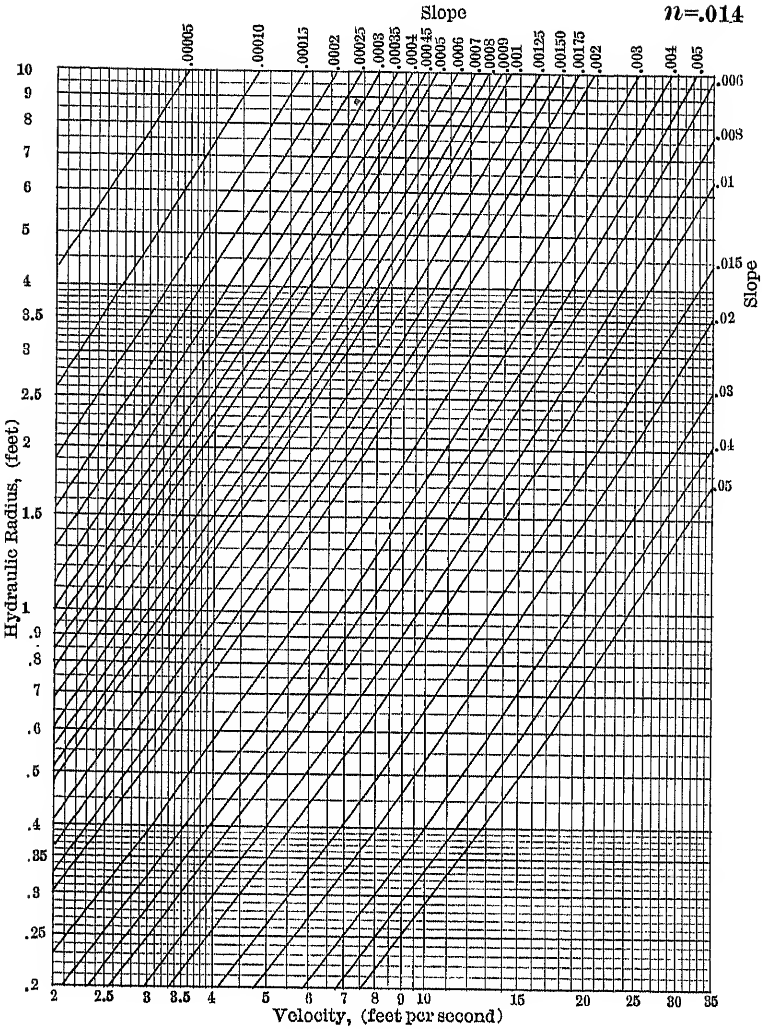

Slope
n=.014
.00005
.00010
.00015
.0002
.00025
.0003
.00035
.0004
.00045
.0005
.0006
.0007
.0008
.0009
.001
.00125
.00150
.00175
.002
.003
.004
.005
.006
.008
.01
.015
.02
.03
.04
.05
Slope
10
9
8
7
6
5
4
3.5
3
2.5
2
1.5
1
.9
.8
.7
.6
.5
.4
.35
.3
.25
.2
Hydraulic Radius, (feet)
2
2.5
3
3.5
4
5
6
7
8
9
10
15
20
25
30
35
Velocity, (feet per second)

FIG. 7.

Suggestion:

$n = .015$ for straight and regular channels of ordinary brickwork, smooth stonework, rough concrete work, and foul and slightly tuberculated iron.

VALUES OF C IN THE FORMULA $V = C\sqrt{RS}$

R	SLOPE					
	.00005	.0001	.0002	.0004	.001	.01 and over
0.1	39	44	48	50	54	54
0.2	51	57	61	65	66	67
0.3	59	65	69	73	74	76
0.4	66	72	76	79	80	82
0.6	76	81	85	87	88	90
0.8	83	88	91	93	94	95
1.0	89	93	96	98	99	99
1.5	99	103	105	106	108	107
2.0	107	109	111	112	112	112
3.0	118	119	119	119	119	119
4.0	126	125	125	124	124	123
6.0	137	134	132	130	130	129
10.0	149	143	140	138	136	136
20.0	165	154	149	146	144	143

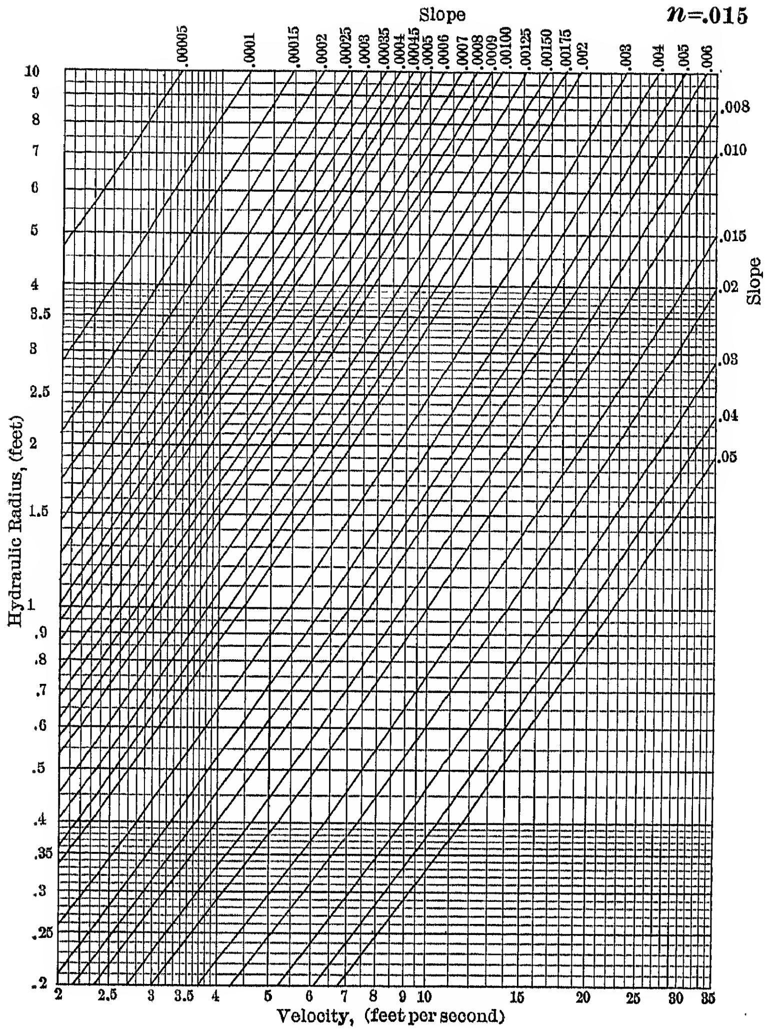

Slope
n=.015
.00005
.0001
.00015
.0002
.00025
.0003
.00035
.0004
.00045
.0005
.0006
.0007
.0008
.0009
.00100
.00125
.00150
.00175
.002
.003
.004
.005
.006
.008
.010
.015
.02
.03
.04
.05
Slope
Hydraulic Radius, (feet)
10
9
8
7
6
5
4
3.5
3
2.5
2
1.5
1
.9
.8
.7
.6
.5
.4
.35
.3
.25
.2
2
2.5
3
3.5
4
5
6
7
8
9
10
15
20
25
30
35
Velocity, (feet per second)

FIG. 8.

Suggestion:

$n = .020$ for channels of compact sand and fine gravel, rough set rubble, ruined masonry, rough tuberculated iron, and canals in earth in good condition lined with well-packed gravel, partly covered with sediment, and free from vegetation.

VALUES OF C IN THE FORMULA $V = C\sqrt{RS}$

R	Slope					
	.00005	.0001	.0002	.0004	.001	.01 and over
0.1	26	30	32	34	36	36
0.2	35	39	42	44	45	46
0.3	41	45	48	50	51	52
0.4	46	50	53	55	56	57
0.6	53	57	60	62	63	64
0.8	59	63	65	67	68	68
1.0	64	67	69	70	71	72
1.5	72	75	77	78	78	79
2.0	79	81	82	83	83	83
3.0	88	89	89	89	89	89
4.0	95	94	94	94	93	93
6.0	105	102	100	99	99	99
10.0	116	111	108	107	105	105
20.0	131	122	117	115	113	112

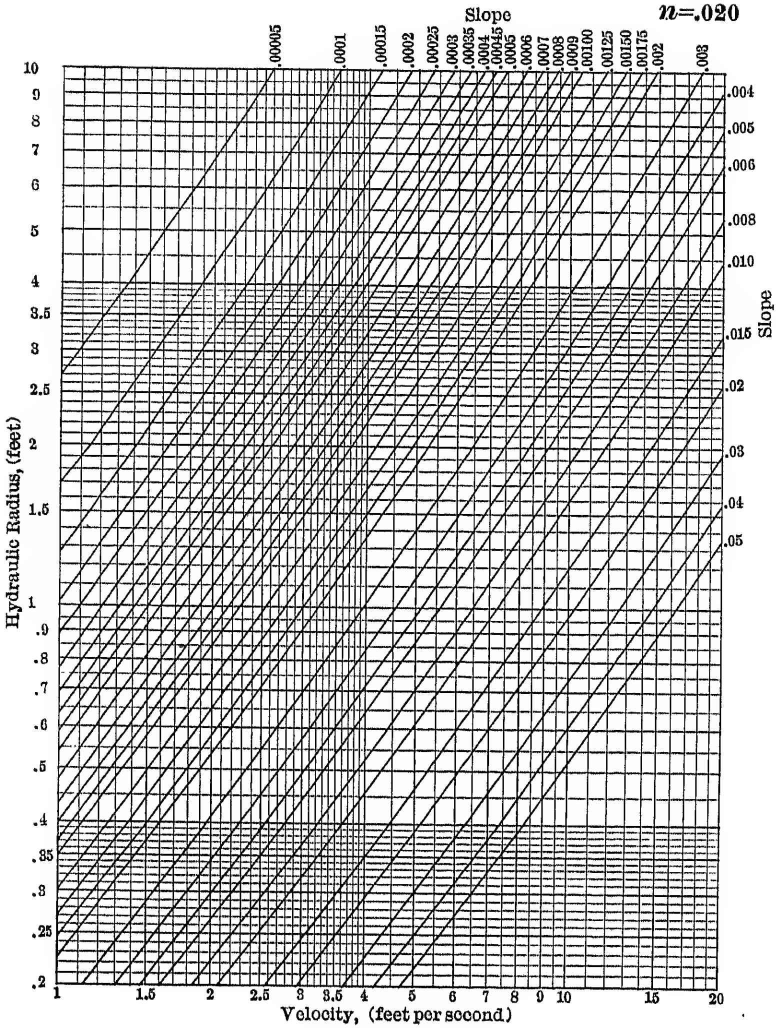

Slope
n=.020
.00005
.0001
.00015
.0002
.00025
.0003
.00035
.0004
.00045
.0005
.0006
.0007
.0008
.0009
.00100
.00125
.00150
.00175
.002
.003
.004
.005
.006
.008
.010
.015
.02
.03
.04
.05
Slope
Hydraulic Radius, (feet)
10
9
8
7
6
5
4
3.5
3
2.5
2
1.5
1
.9
.8
.7
.6
.5
.4
.35
.3
.25
.2
1
1.5
2
2.5
3
3.5
4
5
6
7
8
9
10
15
20
Velocity, (feet per second)

FIG. 9.

Suggestion:

$n = .0225$ for canals in earth in fair condition lined with sediment and occasional patches of algæ, or composed of firm gravel without vegetation. A common figure for earth canals.

VALUES OF C IN THE FORMULA $V = C\sqrt{RS}$

R	Slope					
	.00005	.0001	.0002	.0004	.001	.01 and over
0.1	22	25	27	29	30	31
0.2	30	33	36	37	39	39
0.3	36	39	42	43	44	45
0.4	40	43	46	47	48	49
0.6	46	50	52	54	55	55
0.8	52	55	57	58	59	60
1.0	56	59	60	62	62	63
1.5	64	66	67	68	69	69
2.0	70	71	72	73	73	74
3.0	79	79	79	79	79	79
4.0	85	84	84	84	83	83
6.0	94	92	90	89	89	88
10.0	105	100	98	96	95	94
20.0	120	111	106	104	102	101

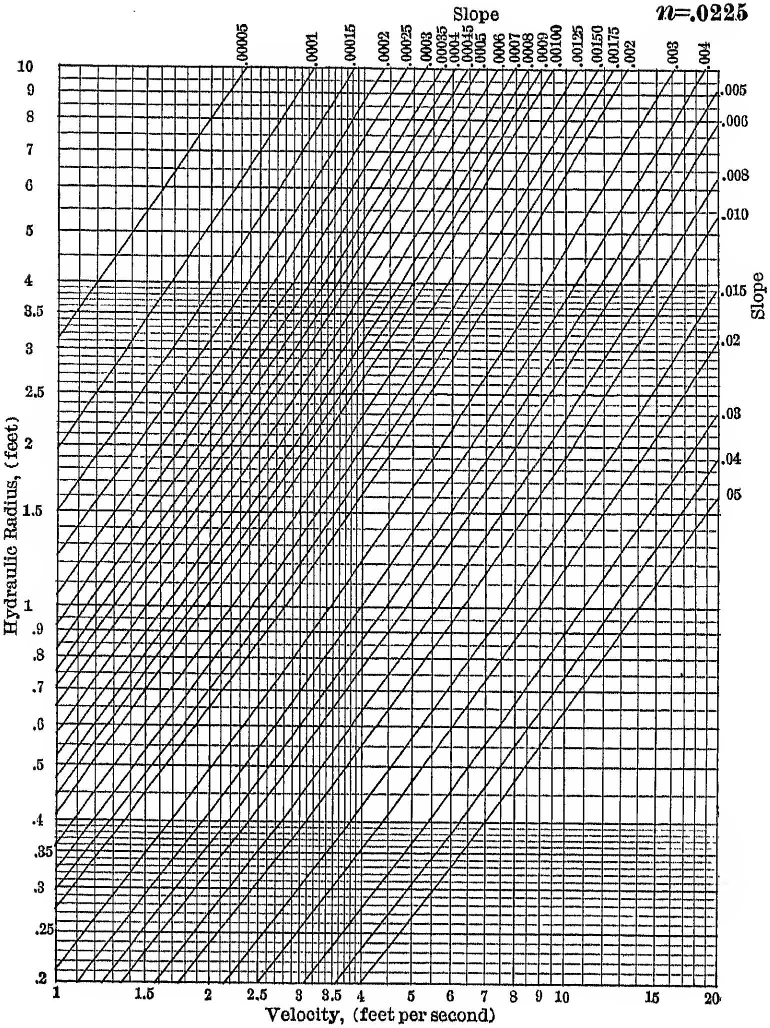

Slope
n=.0225
.00005
.0001
.00015
.0002
.00025
.0003
.00035
.0004
.00045
.0005
.0006
.0007
.0008
.0009
.00100
.00125
.00150
.00175
.002
.003
.004
.005
.006
.008
.010
.015
.02
.03
.04
05
Slope
Hydraulic Radius, (feet)
10
9
8
7
6
5
4
3.5
3
2.5
2
1.5
1
.9
.8
.7
.6
.5
.4
.35
.3
.25
.2
1
1.5
2
2.5
3
3.5
4
5
6
7
8
9
10
15
20
Velocity, (feet per second)

FIG. 10.

Suggestion:

$n = .025$ for canals in earth of tolerably uniform cross-section, slope and alignment in average condition,—the water slopes being lined with sediment and minute algæ, or composed of loose, coarse gravel; and for very smooth rock sections.

VALUES OF C IN THE FORMULA $V = C\sqrt{RS}$

R	Slope					
	.00005	.0001	.0002	.0004	.001	.01 and over
0.1	20	22	24	25	27	27
0.2	26	29	31	32	34	34
0.3	31	34	36	37	39	39
0.4	35	38	40	42	43	44
0.6	41	44	46	47	48	49
0.8	46	48	50	51	52	53
1.0	49	52	54	55	56	56
1.5	57	59	60	61	62	62
2.0	62	64	64	65	66	66
3.0	71	71	72	71	71	71
4.0	77	76	76	76	75	76
6.0	85	84	82	81	81	81
10.0	96	92	89	88	87	86
20.0	110	102	98	96	94	93

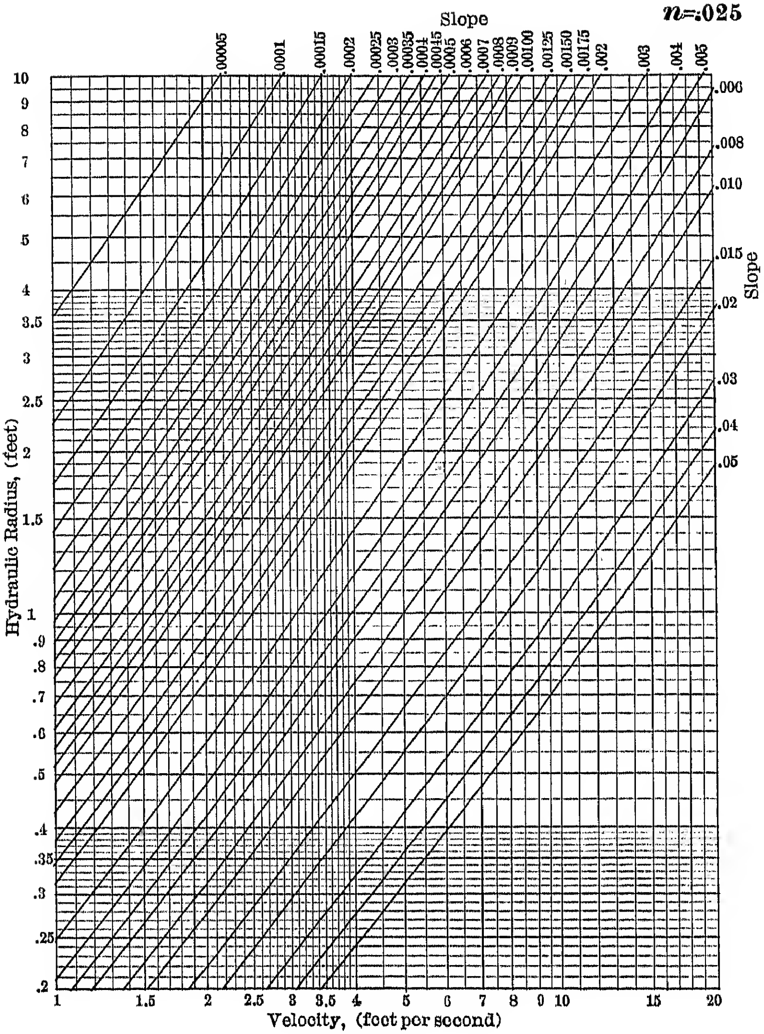

n=.025
Slope
.00005
.0001
.00015
.0002
.00025
.0003
.00035
.0004
.00045
.0005
.0006
.0007
.0008
.0009
.00100
.00125
.00150
.00175
.002
.003
.004
.005
.006
.008
.010
.015
.02
.03
.04
.05
Slope
Hydraulic Radius, (feet)
10
9
8
7
6
5
4
3.5
3
2.5
2
1.5
1
.9
.8
.7
.6
.5
.4
.35
.3
.25
.2
1
1.5
2
2.5
3
3.5
4
5
6
7
8
9
10
15
20
Velocity, (feet per second)

FIG. 11.

Suggestion:

n = .030 for canals in earth in poor condition, having the bed partly covered with débris, or having comparatively smooth sides and bed, but the channel partly obstructed with grass, weeds, or aquatic plants; and for average rock sections.

VALUES OF C IN THE FORMULA $V = C\sqrt{RS}$

R	Slope					
	.00005	.0001	.0002	.0004	.001	.01 and over
0.1	16	17	18	19	21	21
0.2	21	23	25	25	27	27
0.3	25	27	29	30	30	31
0.4	28	31	32	33	34	35
0.6	33	35	37	38	39	39
0.8	37	39	41	42	42	43
1.0	40	42	44	45	45	45
1.5	47	48	49	50	50	51
2.0	51	53	54	54	54	55
3.0	59	59	59	59	59	59
4.0	64	64	63	63	63	63
6.0	72	71	69	69	68	68
10.0	82	78	76	75	74	74
20.0	96	89	85	83	81	80

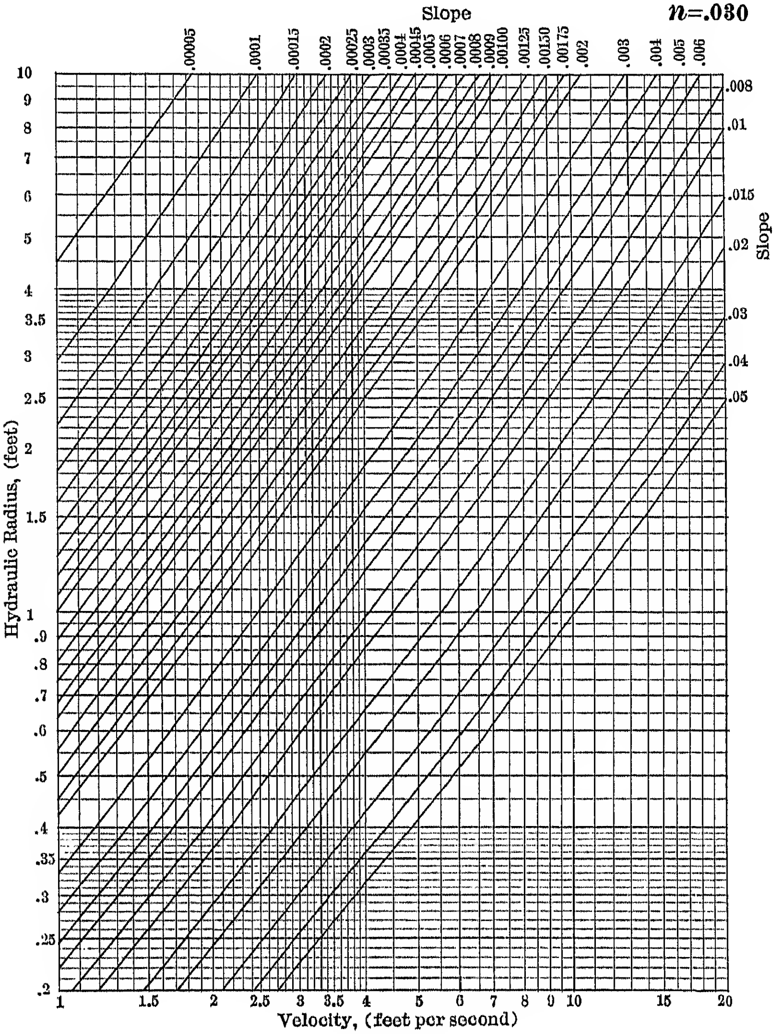

Slope
n=.030
.00005
.0001
.00015
.0002
.00025
.0003
.00035
.0004
.00045
.0005
.0006
.0007
.0008
.0009
.00100
.00125
.00150
.00175
.002
.003
.004
.005
.006
.008
.01
.015
.02
.03
.04
.05
Slope
Hydraulic Radius, (feet)
10
9
8
7
6
5
4
3.5
3
2.5
2
1.5
1
.9
.8
.7
.6
.5
.4
.35
.3
.25
.2
1
1.5
2
2.5
3
3.5
4
5
6
7
8
9
10
15
20
Velocity, (feet per second)

FIG. 12.

Suggestion:

n = .035 for canals in earth in bad order and regimen, having the channel strewn with stones and detritus or about one-third full of vegetation; and for rough rock sections.

VALUES OF C IN THE FORMULA $V = C\sqrt{RS}$

R	Slope					
	.00005	.0001	.0002	.0004	.001	.01 and over
0.1	13	14	15	16	17	17
0.2	18	19	21	21	22	22
0.3	21	22	24	24	25	25
0.4	24	25	27	27	28	29
0.6	28	30	31	31	32	33
0.8	31	33	34	35	35	35
1.0	34	35	37	37	38	38
1.5	40	41	42	42	43	43
2.0	44	45	45	45	46	46
3.0	50	51	51	51	51	51
4.0	56	55	55	55	54	55
6.0	63	61	60	60	59	59
10.0	72	69	67	66	65	65
20.0	85	79	76	73	72	71

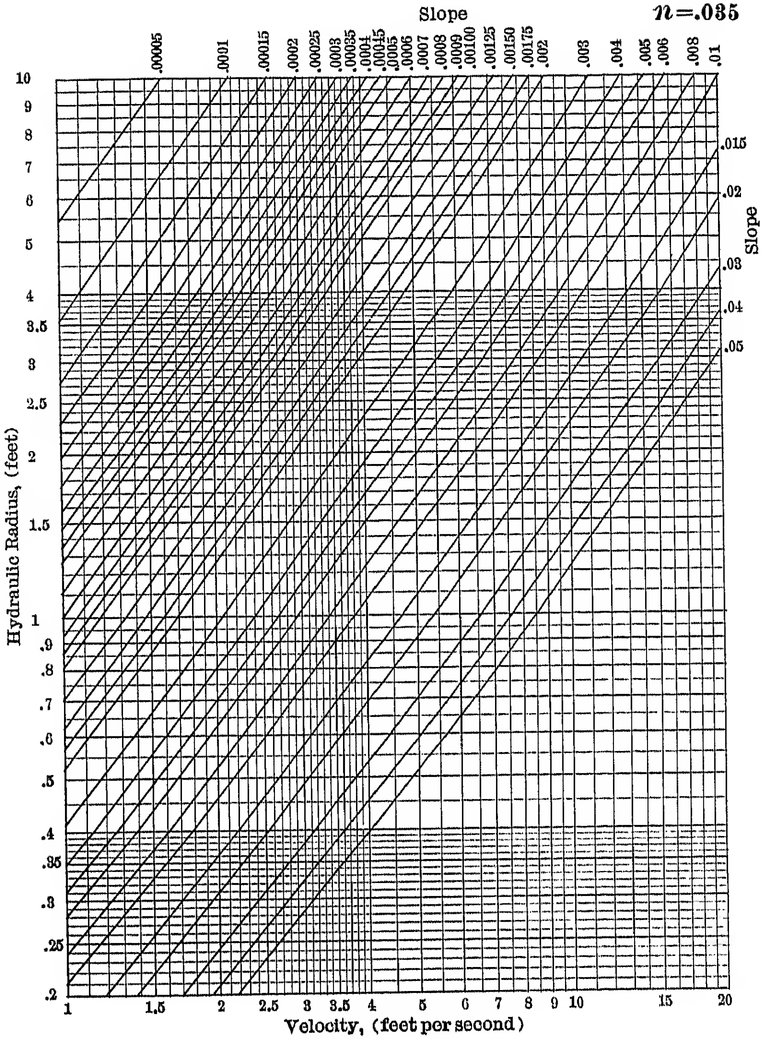

Slope
n=.035
.00005
.0001
.00015
.0002
.00025
.0003
.00035
.0004
.00045
.0005
.0006
.0007
.0008
.0009
.00100
.00125
.00150
.00175
.002
.003
.004
.005
.006
.008
.01
.015
.02
.03
.04
.05
Slope
Hydraulic Radius, (feet)
10
9
8
7
6
5
4
3.5
3
2.5
2
1.5
1
.9
.8
.7
.6
.5
.4
.35
.3
.25
.2
1
1.5
2
2.5
3
3.5
4
5
6
7
8
9
10
15
20
Velocity, (feet per second)

FIG. 13.

TABLE 21

VALUES OF C FOR USE IN THE CHEZY FORMULA $V = C\sqrt{RS}$

R \ n	.009	.010	.011	.012	.013	.014	.015	.017	.020	.0225	.025	.030	.035	.040
Slope S = .00005 = 1 in 20,000 = 0.264 feet per mile														
.1	78	67	59	52	47	43	39	33	26	22	20	16	13	11
.2	100	87	77	68	62	56	51	44	35	30	26	21	18	15
.3	114	99	88	79	71	65	59	50	41	36	31	25	21	18
.4	124	109	97	88	79	72	66	57	46	40	35	28	24	20
.6	139	122	109	98	90	82	76	65	53	46	41	33	28	24
.8	150	133	119	107	98	90	83	71	59	52	46	37	31	27
1.0	158	140	126	114	104	96	89	77	64	56	49	40	34	29
1.5	173	154	139	126	116	107	99	87	72	64	57	47	40	34
2	184	164	148	135	124	115	107	94	79	70	62	51	44	38
3	198	178	161	148	136	127	118	104	88	79	71	59	50	44
*3.28	201	181	164	151	139	129	121	106	91	81	72	60	52	46
4	207	187	170	156	145	135	126	111	95	85	77	64	56	49
6	220	199	182	168	156	146	137	122	105	94	85	72	63	56
10	234	212	195	181	169	158	149	134	116	105	96	82	72	64
20	250	228	211	196	184	174	165	149	131	120	110	96	85	77
50	266	245	228	213	201	190	181	165	148	136	127	112	101	93
100	275	254	237	222	210	200	190	175	158	146	137	123	112	104
Slope S = .0001 = 1 in 10,000 = 0.528 feet per mile														
.1	90	78	68	60	54	49	44	37	30	25	22	17	14	12
.2	112	98	86	76	69	63	57	48	39	33	29	23	19	16
.3	125	109	97	87	78	72	65	56	45	39	34	27	22	19
.4	136	119	106	95	86	79	72	62	50	43	38	31	25	22
.6	149	131	118	105	96	88	81	70	57	50	44	35	30	25
.8	158	140	126	114	103	95	88	76	63	55	48	39	33	28
1.0	166	147	132	120	109	101	93	81	67	59	52	42	35	31
1.5	178	159	144	130	120	111	103	89	75	66	59	48	41	35
2	187	168	151	138	127	118	109	96	81	71	64	53	45	39
3	198	178	162	149	137	127	119	104	89	79	71	59	51	45
4	206	186	169	155	143	134	125	111	94	84	76	64	55	49
6	215	195	178	164	152	142	134	119	102	92	84	71	61	54
10	226	205	188	174	162	152	143	128	111	100	92	78	69	62
20	237	216	200	185	173	163	154	139	122	111	102	89	79	71
50	249	227	211	197	185	175	166	151	134	123	114	100	91	83
100	255	234	218	204	191	181	172	158	140	130	121	108	98	91
Slope S = .0002 = 1 in 5,000 = 1,056 feet per mile														
.1	99	85	74	65	59	53	48	41	32	27	24	18	15	12
.2	121	105	93	83	74	67	61	52	42	36	31	25	21	17
.3	133	116	103	92	83	76	69	59	48	42	36	29	24	20
.4	143	125	112	100	91	83	76	65	53	46	40	32	27	23
.6	155	138	122	111	100	92	85	73	60	52	46	37	31	26
.8	164	145	131	118	107	99	91	79	65	57	50	41	34	29
1.0	170	151	136	123	113	104	96	83	69	60	54	44	37	32
1.5	181	162	146	133	122	113	105	91	77	67	60	49	42	36
2	188	170	154	140	129	119	111	97	82	72	64	54	45	40
3	200	179	163	149	137	128	119	105	89	79	72	59	51	45
4	205	185	168	155	143	133	125	111	94	84	76	63	55	48
6	213	193	176	162	150	140	132	117	100	90	82	69	60	53
10	222	201	185	170	158	148	140	125	108	98	89	76	67	60
20	231	210	194	180	168	158	149	134	117	106	98	85	76	68
50	240	220	203	189	177	167	158	143	126	116	108	94	85	78
100	245	224	208	194	182	172	163	148	131	121	113	99	90	83

* Values of C are the same for all slopes when R = 3.28 feet.

TABLE 21 (*Concluded*)

VALUES OF C FOR USE IN THE CHEZY FORMULA $V = C\sqrt{RS}$

R \ n	.009	.010	.011	.012	.013	.014	.015	.017	.020	.0225	.025	.030	.035	.040
Slope S = .0004 = 1 in 2,500 = 2.112 feet per mile														
.1	104	89	78	69	62	56	50	43	34	29	25	19	16	13
.2	126	110	97	87	78	71	65	54	44	37	32	25	21	18
.3	138	120	107	96	87	79	73	62	50	43	37	30	24	21
.4	148	129	115	104	94	86	79	68	55	47	42	33	27	23
.6	157	140	126	113	103	95	87	75	62	54	47	38	31	27
.8	166	148	133	121	110	101	93	81	67	58	51	42	35	30
1.0	172	154	138	125	115	106	98	85	70	62	55	45	37	32
1.5	183	164	148	135	124	114	106	93	78	68	61	50	42	37
2	190	170	154	141	130	120	112	98	83	73	65	54	45	40
3	199	179	162	149	138	128	119	105	89	79	71	59	51	45
4	204	184	168	154	142	133	124	110	94	84	76	63	55	48
6	211	191	175	161	149	139	130	116	99	89	81	69	60	53
10	219	199	183	168	157	146	138	123	107	96	88	75	66	59
20	227	207	190	176	164	154	146	131	115	104	96	83	73	66
50	235	215	198	184	173	162	154	139	123	112	104	91	82	75
100	239	219	203	189	177	167	158	143	127	116	108	96	87	80
Slope S = .001 = 1 in 1,000 = 5.28 feet per mile														
.1	110	94	83	73	65	59	54	45	36	30	27	21	17	14
.2	129	113	99	89	81	73	66	57	45	39	34	27	22	18
.3	141	124	109	98	89	81	74	63	51	44	39	30	25	21
.4	150	131	117	105	96	88	80	69	56	48	43	34	28	24
.6	161	142	127	115	104	96	88	76	63	55	48	39	32	27
.8	169	150	134	122	111	102	94	82	68	59	52	42	35	30
1.0	175	155	139	127	116	107	99	86	71	62	56	45	38	33
1.5	184	165	149	136	124	115	108	93	78	69	62	50	43	37
2	191	171	155	142	130	121	112	98	83	73	66	54	46	40
3	199	179	163	149	138	128	119	105	89	79	71	59	51	45
4	204	184	168	154	142	133	124	110	93	83	75	63	54	48
6	211	190	174	160	149	139	130	116	99	89	81	68	59	52
10	218	197	181	167	155	145	136	122	105	95	87	74	65	58
20	225	205	188	175	163	153	144	129	113	102	94	81	72	65
50	232	212	196	182	170	160	151	137	120	110	101	89	79	72
100	236	216	200	186	174	164	155	141	124	114	105	94	85	77
Slope S = .01 = 1 in 100 = 52.8 feet per mile														
.1	110	95	83	74	66	60	54	46	36	31	27	21	17	14
.2	130	114	100	90	81	74	67	57	46	39	34	27	22	19
.3	143	125	111	100	90	83	76	64	52	45	39	31	25	22
.4	151	133	119	107	98	89	82	70	57	49	44	35	29	24
.6	162	143	129	116	106	98	90	77	64	55	49	39	33	28
.8	170	151	135	123	112	103	95	82	68	60	53	43	35	31
1.0	175	156	141	128	117	108	99	87	72	63	56	45	38	33
1.5	185	165	149	136	125	116	107	94	79	69	62	51	43	37
2	191	171	155	142	130	121	112	99	83	74	66	55	46	40
3	199	179	162	149	138	128	119	105	89	79	71	59	51	45
4	204	184	167	154	142	132	123	109	93	83	76	63	55	48
6	210	190	173	160	148	138	129	115	99	88	81	68	59	52
10	217	196	180	166	154	145	136	121	105	94	86	74	65	58
20	225	204	187	173	161	152	143	128	112	101	93	80	71	64
50	231	210	194	181	168	158	150	135	119	108	100	87	78	71
100	235	214	197	184	172	162	153	139	122	112	104	91	82	75

NOTE.—For slopes greater than .01 C remains practically constant.

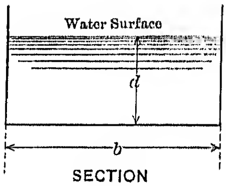
Formulæ:

$$A = b\,d$$

$$P = b + 2\,d$$

$$r = \frac{A}{P} = \frac{b\,d}{b + 2\,d}$$

$$Q = A\,V$$



SECTION

Problem:

$b = 4$

$d = 2.25$

What is the value of r and what is the value of the discharge Q when $V = 1.5$ feet per second?

Solution:

Enter diagram at depth = 2.25; thence horizontally to $b = 4$; read $r = 1.06$ and $A = 9$; thence vertically to $V = 1.5$, and read $Q = 13.5$.

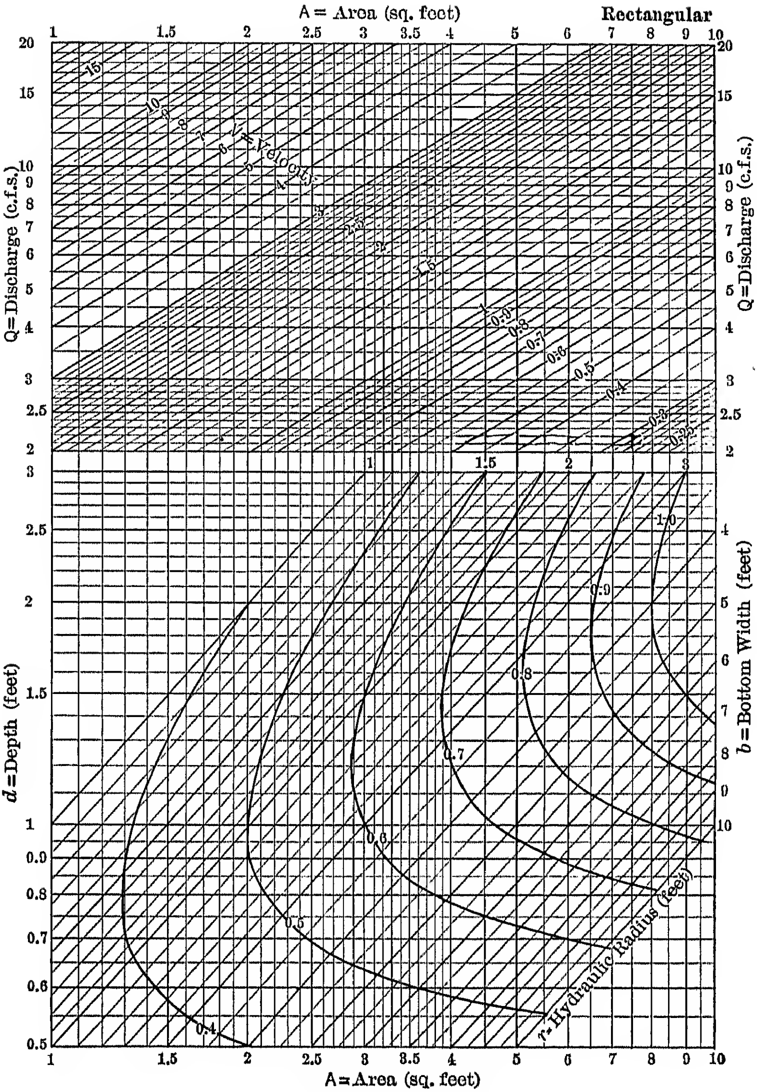


FIG. 14 (Part 1 of 3).—Hydraulic Elements of Rectangular Sections.

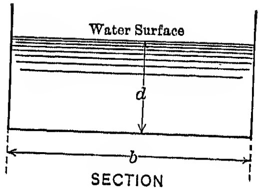
Formulæ:

$$A = b\,d$$

$$P = b + 2\,d$$

$$r = \frac{A}{P} = \frac{b\,d}{b + 2\,d}$$

$$Q = A\,V$$



Problem:

$$Q = 120$$

$$V = 5.2$$

$$r = 1.7$$

What is the required bottom width b and depth d?

Solution:

Enter the upper diagram at $Q = 120$; thence horizontally to $V = 5.2$; thence vertically downward to a point halfway between $r = 1.6$ and $r = 1.8$, and read $b = 8.5$ and $d = 2.83$.

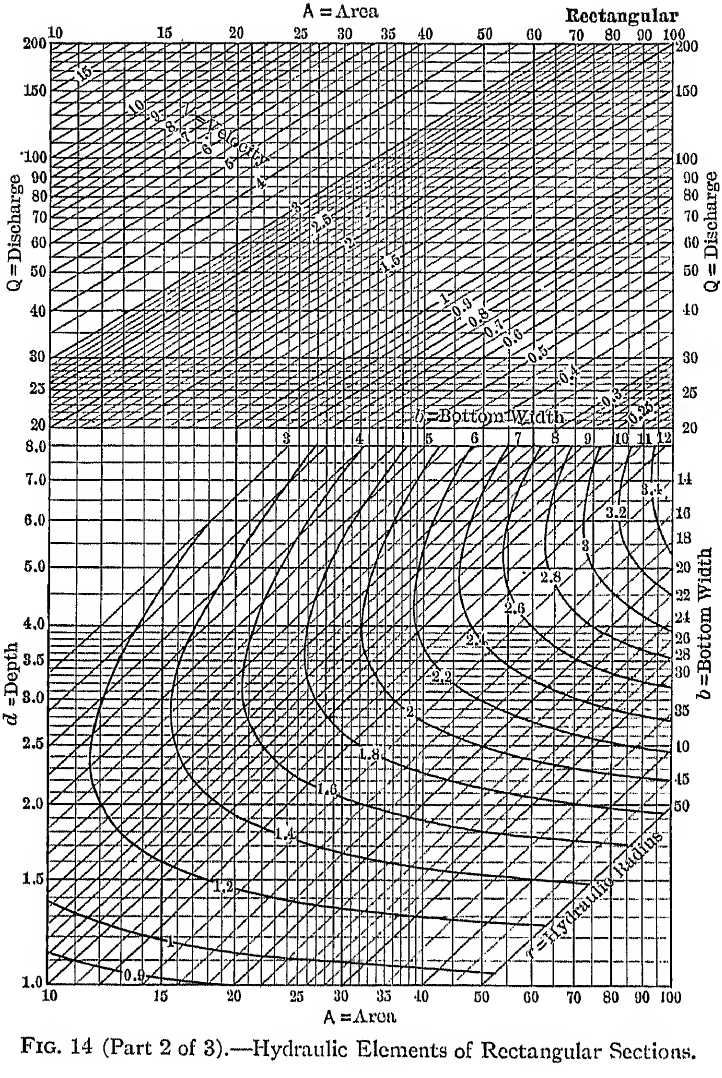


FIG. 14 (Part 2 of 3).—Hydraulic Elements of Rectangular Sections.

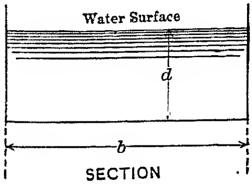
Formulæ:

$$A = b\,d$$

$$P = b + 2\,d$$

$$r = \frac{A}{P} = \frac{b\,d}{b + 2\,d}$$

$$Q = A\,V$$



Problem:

$Q = 850$

$V = 2.2$

$b = 80$

Find d and r.

Solution:

Enter upper diagram at $Q = 850$; thence horizontally to $V = 2.2$; thence vertically downward to $b = 80$, and read $d = 4.85$ and $r = 4.32$.

(NOTE.—The above values of r and d may be in error by one or two figures in the third digit. That is, r may be 4.31 or 4.33, and d may be 4.84 or 4.86, depending upon the personal equation of the reader of the diagram. These differences, however, are of no practical importance.)

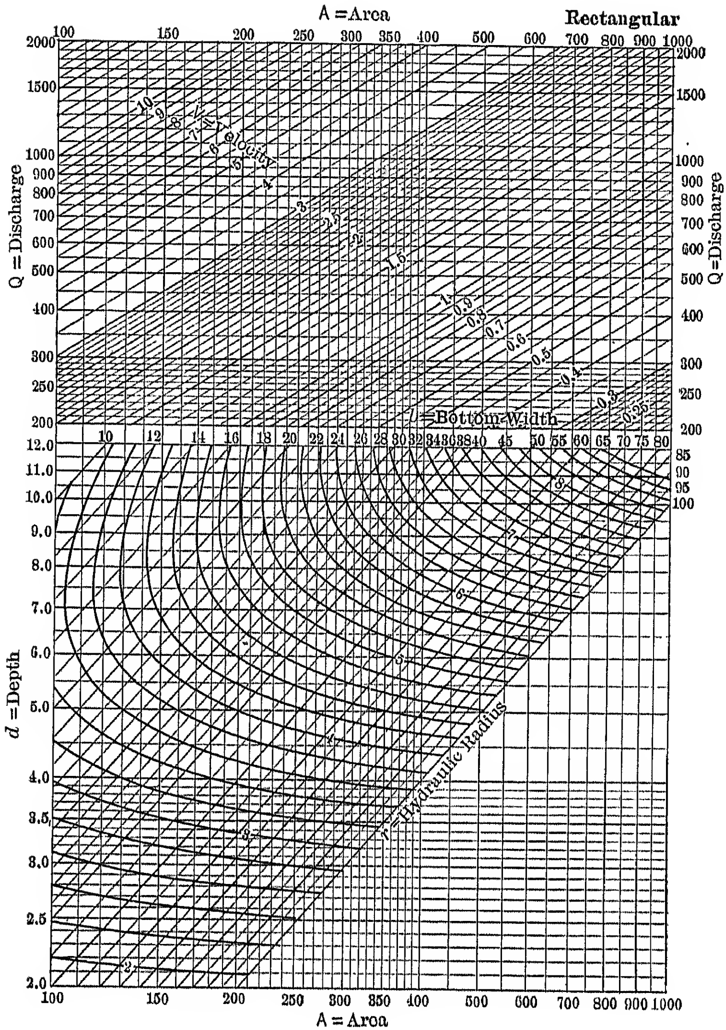
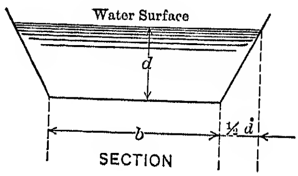


FIG. 14 (Part 3 of 3).—Hydraulic Elements of Rectangular Sections.

Formulæ:

$$A = b\,d + 0.5\,d^2$$
$$P = b + 2.24\,d$$
$$r = \frac{A}{P} = \frac{b\,d + 0.5\,d^2}{b + 2.24\,d}$$
$$Q = A\,V$$



Problem:

$Q = 9.2$

$A = 8.5$

$b = 4$

Find d, r, and V.

Solution:

Enter the diagram at $Q = 9.2$; thence horizontally to $A = 8.5$ and read $V = 1.08$; thence vertically downward to $b = 4$, and read $d = 1.75$ and $r = 1.08$.

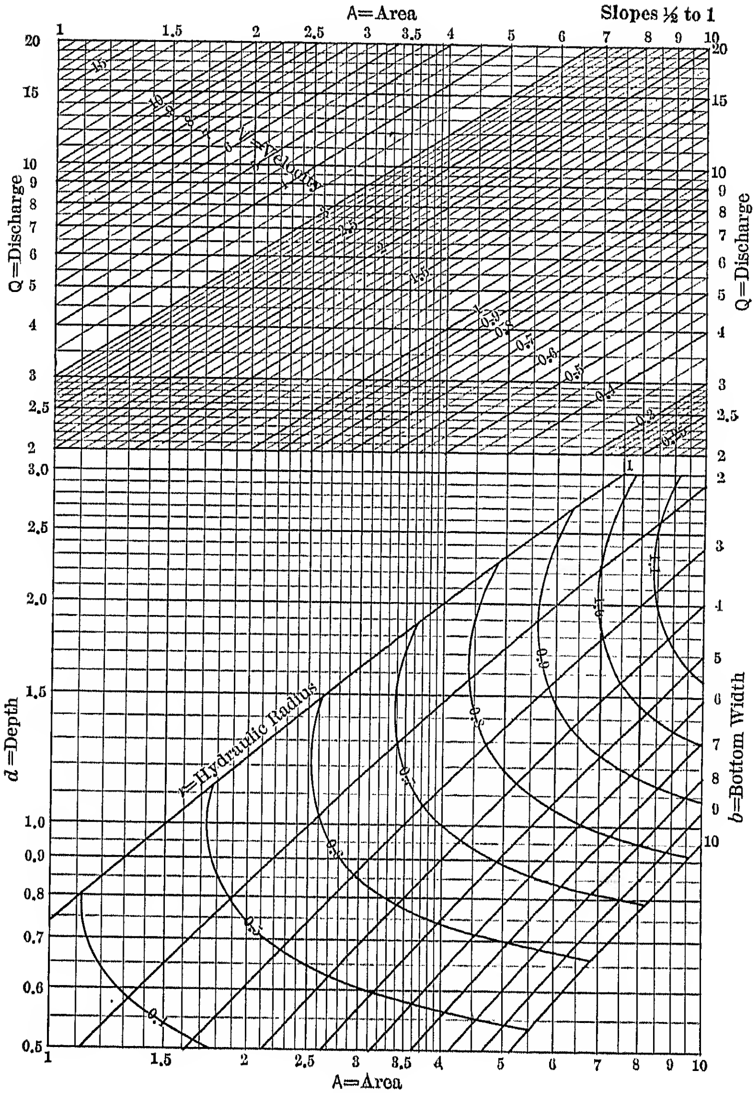
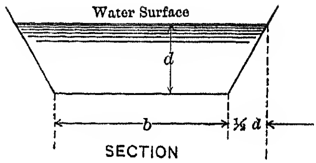


Fig. 15 (Part 1 of 3).—Hydraulic Elements of Trapezoidal Sections.

Formulæ:

$$A = b\,d + 0.5\,d^2$$
$$P = b + 2.24\,d$$
$$r = \frac{A}{P} = \frac{b\,d + 0.5\,d^2}{b + 2.24\,d}$$
$$Q = A\,V$$



Problem:

$Q = 260$

$V = 24$

$d = 1.4$

Find b and r.

Solution:

Velocities over 20 feet per second are not indicated on the diagram, but it can be used for any velocity which, divided into the discharge, will give an area between 10 and 100 square feet, as illustrated in the following solution of the above problem.

If we divide both Q and V by 10 the quotient $\frac{Q}{V} = A$ remains the same. We therefore enter the diagram with $Q = 26$ instead of 260; thence horizontally to $V = 2.4$ instead of 24; thence vertically downward to $d = 1.4$, and read $b = 7$ and $r = 1.05$.

If V were greater than 26, say 28, making $\frac{Q}{V}$ less than 10, we would divide both Q and V by 100 and use Fig. 12, entering the diagram with $Q = 2.6$ and $V = 0.28$. The remaining steps would be the same as above.

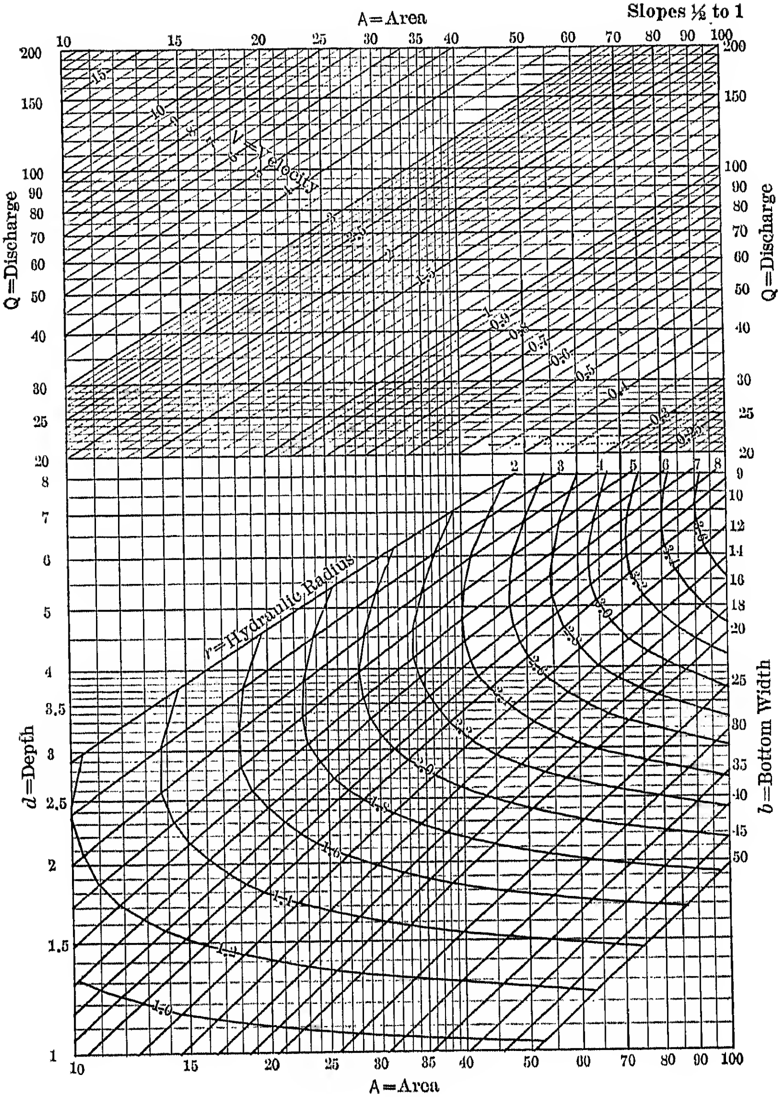


FIG. 15 (Part 2 of 3).—Hydraulic Elements of Trapezoidal Sections.

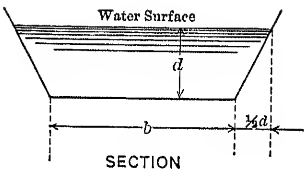
Formulæ:

$$A = b\,d + 0.5\,d^2$$

$$P = b + 2.24\,d$$

$$r = \frac{A}{P} = \frac{b\,d + 0.5\,d^2}{b + 2.24\,d}$$

$$Q = A\,V$$



Problem:

$b = 50$

$d = 10.5$

$V = 4.5$

Find r and Q.

Solution:

Enter the diagram at $d = 10.5$; thence horizontally to $b = 50$ and read $r = 7.9$. Continuing now vertically we note that the $V = 4.5$ line is not intersected. We therefore divide our velocity by 10 and stop at $V = 0.45$ and read $Q = 260$. Since this value of Q corresponds to a velocity of 0.45, which is only one-tenth the velocity given, the actual value of Q is $260 \times 10 = 2600$.

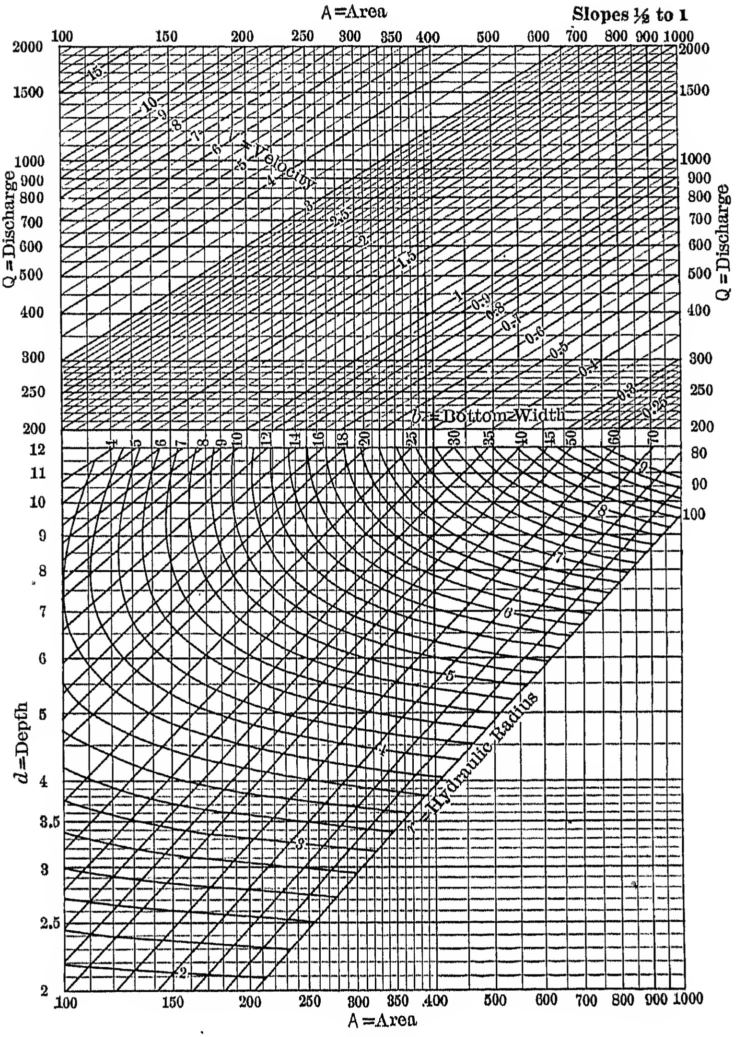


FIG. 15 (Part 3 of 3).—Hydraulic Elements of Trapezoidal Sections.

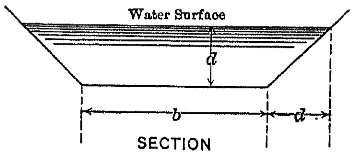
Formulæ:

$$A = b\,d + d^2$$

$$P = b + 2.83\,d$$

$$r = \frac{b\,d + d^2}{b + 2.83\,d}$$

$$Q = A\,V$$



Problem:

$b = 2$

$d = 1.5$

Find A and r.

Solution:

Enter the diagram at $d = 1.5$; thence horizontally to $b = 2$, and read $A = 5.2$ and $r = 0.84$.

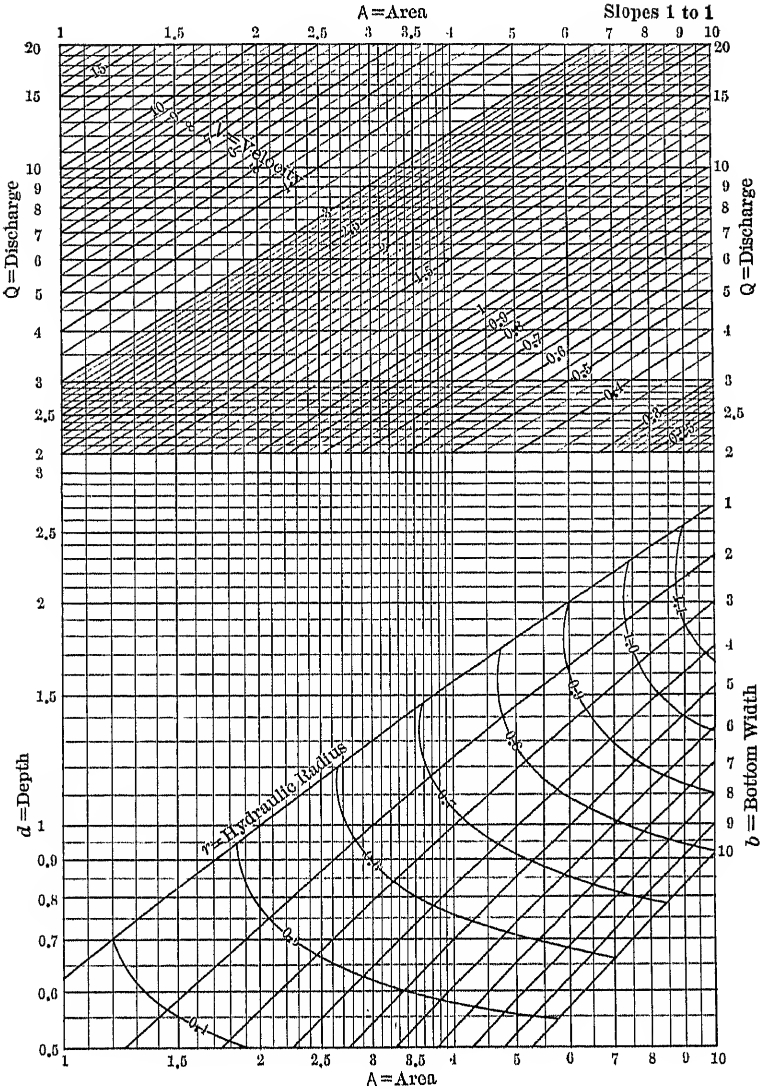


FIG. 16 (Part 1 of 3).—Hydraulic Elements of Trapezoidal Sections.

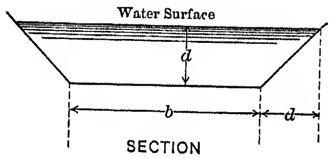
Formulæ:

$$A = b\,d + d^2$$

$$P = b + 2.83\,d$$

$$r = \frac{A}{P} = \frac{b\,d + d^2}{b + 2.83\,d}$$

$$Q = A\,V$$



Problem:

$A = 63$

$r = 2.75$

Find b and d.

Solution:

Enter the diagram at $A = 63$; thence follow vertically to $r = 2.75$ (an imaginary line three-fourths of the distance from 2.6 to 2.8), and read $b = 11.5$ and $d = 4.05$.

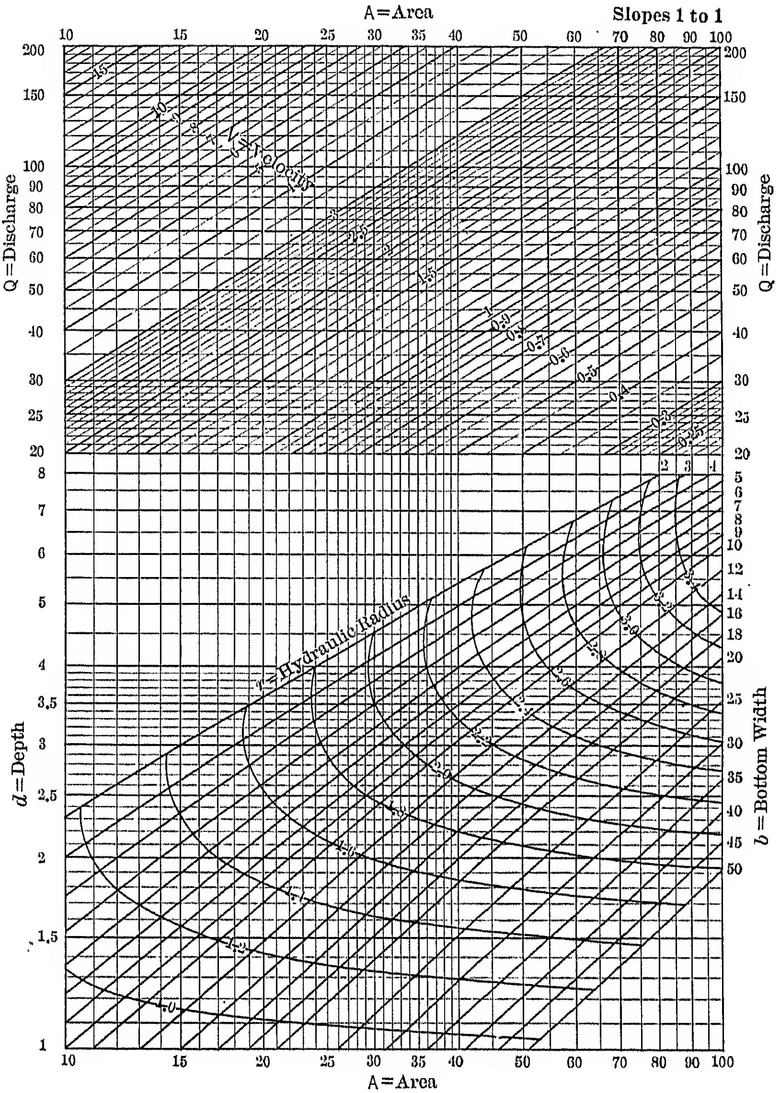


FIG. 16 (Part 2 of 3).—Hydraulic Elements of Trapezoidal Sections.

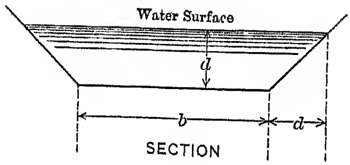
Formulæ:

$$A = b\,d + d^2$$

$$P = b - 2.83\,d$$

$$r = \frac{A}{P} = \frac{b\,d + d^2}{b + 2.83\,d}$$

$$Q = A\,V$$



Problem:

For an area of 140 square feet what combination of bottom width and depth gives the greatest hydraulic radius?

Solution:

Enter the diagram at $A = 140$ and follow vertically to the point indicating the maximum value of r which is when $b = 7$ (to the nearest foot) and $d = 8.8$. The value of r is 4.38.

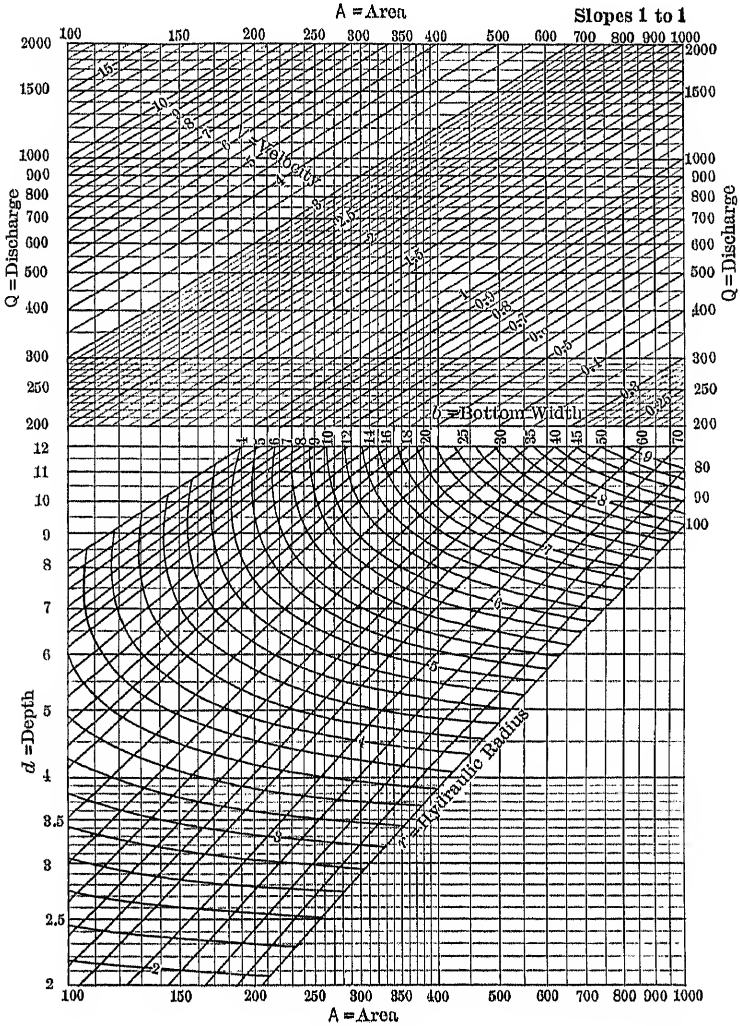


FIG. 16 (Part 3 of 3).—Hydraulic Elements of Trapezoidal Sections.

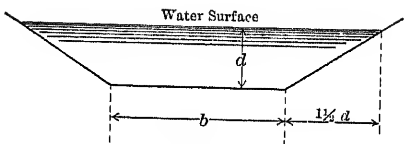
Formulæ:

$$A = b\,d + 1.5\,d^2$$

$$P = b + 3.61\,d$$

$$r = \frac{A}{P} = \frac{b\,d + 1.5\,d^2}{b + 3.61\,d}$$

$$Q = A\,V$$



SECTION

Problem:

It is required to design a canal section to carry 14 c. f. s. with a velocity of 2.2; the section to have a bottom width equal to three times the depth. Find also the hydraulic radius.

Solution:

Enter the diagram at $Q = 14$ and follow horizontally to $V = 2.2$; thence vertically downward to a point which indicates a ratio of bottom width to depth of 3 to 1. We find this to be when $b = 3.6$ and $d = 1.2$. The corresponding hydraulic radius r is found at the same time to be 0.82.

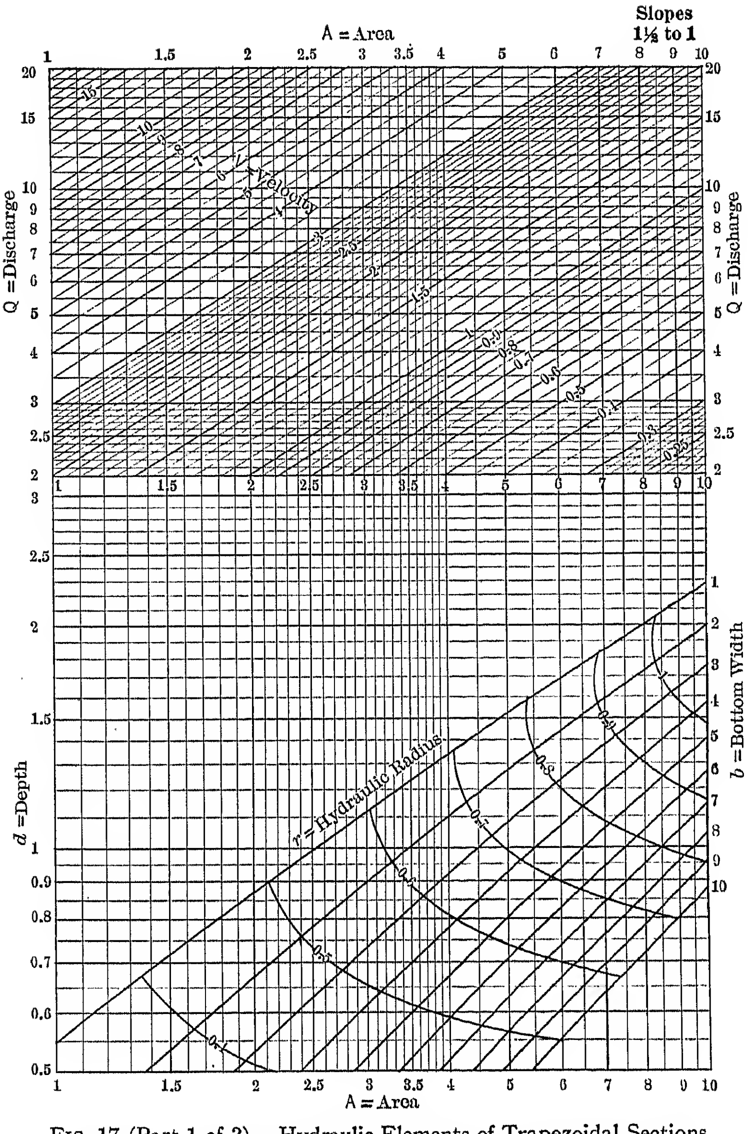
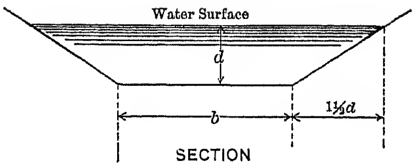


FIG. 17 (Part 1 of 3).—Hydraulic Elements of Trapezoidal Sections.

Formulæ:

$$A = b\,d + 1.5\,d^2$$
$$P = b + 3.61\,d$$
$$r = \frac{A}{P} = \frac{b\,d + 1.5\,d^2}{b + 3.61\,d}$$
$$Q = A\,V$$



Problem:

$Q = 500$

$V = 24$

$r = 1.4$

Find A, b, and d.

Solution:

Neither $Q = 500$ nor $V = 24$ is given in the diagram, but since $A = \frac{Q}{V}$ we may divide both Q and V by 10 before entering the diagram and obtain the required values of A, b, and d. Enter the diagram at $Q = 50$, follow horizontally to $V = 2.4$ and read $A = 20.8$; thence vertically downward to $r = 1.4$, and read $b = 8$ and $d = 1.92$.

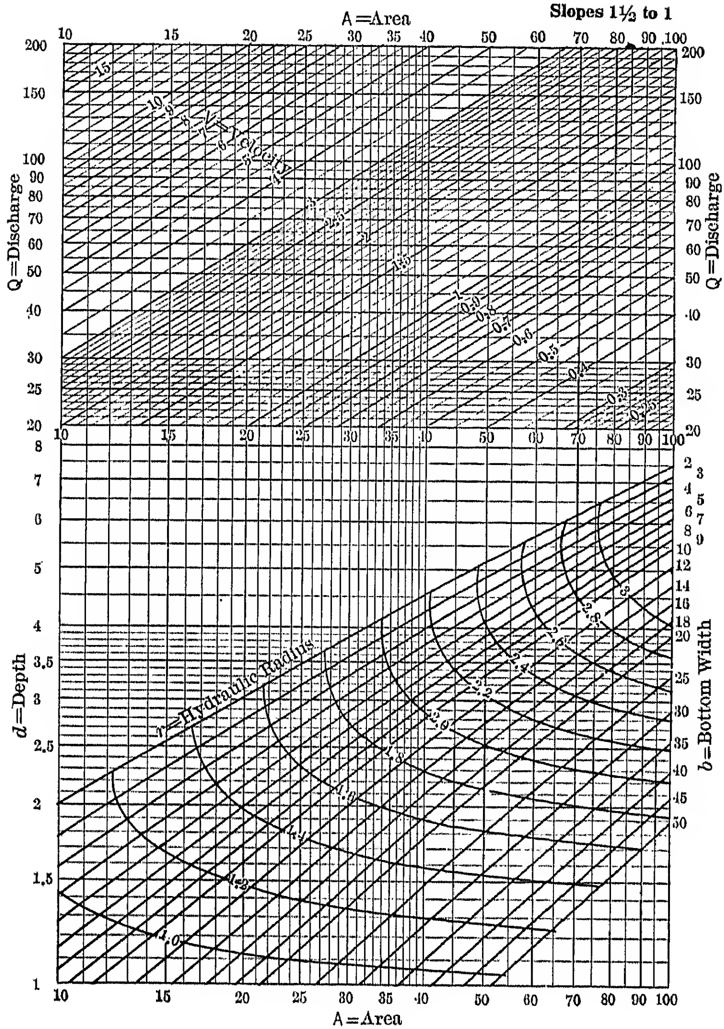


FIG. 17 (Part 2 of 3).—Hydraulic Elements of Trapezoidal Sections.

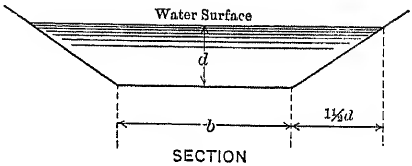
Formulæ:

$$A = b\,d + 1.5\,d^2$$

$$P = b + 3.61\,d$$

$$r = \frac{A}{P} = \frac{b\,d + 1.5\,d^2}{b + 3.61\,d}$$

$$Q = A\,V$$



Problem:

$b = 60$

$d = 10.3$

$V \doteq 3$

Find r, A, and Q.

Solution:

Enter the diagram at $d = 10.3$, follow horizontally to $b = 60$ and read $r = 8.0$ and $A = 780$. Following vertically upward we note that $V = 3$ is not intersected. We, therefore, stop at $V = 0.3$, and read $Q = 235$. Since $Q = 235$ for $V = 0.3$, it will be ten times 235 for $V = 3$. The required value of Q, therefore, is 2350.

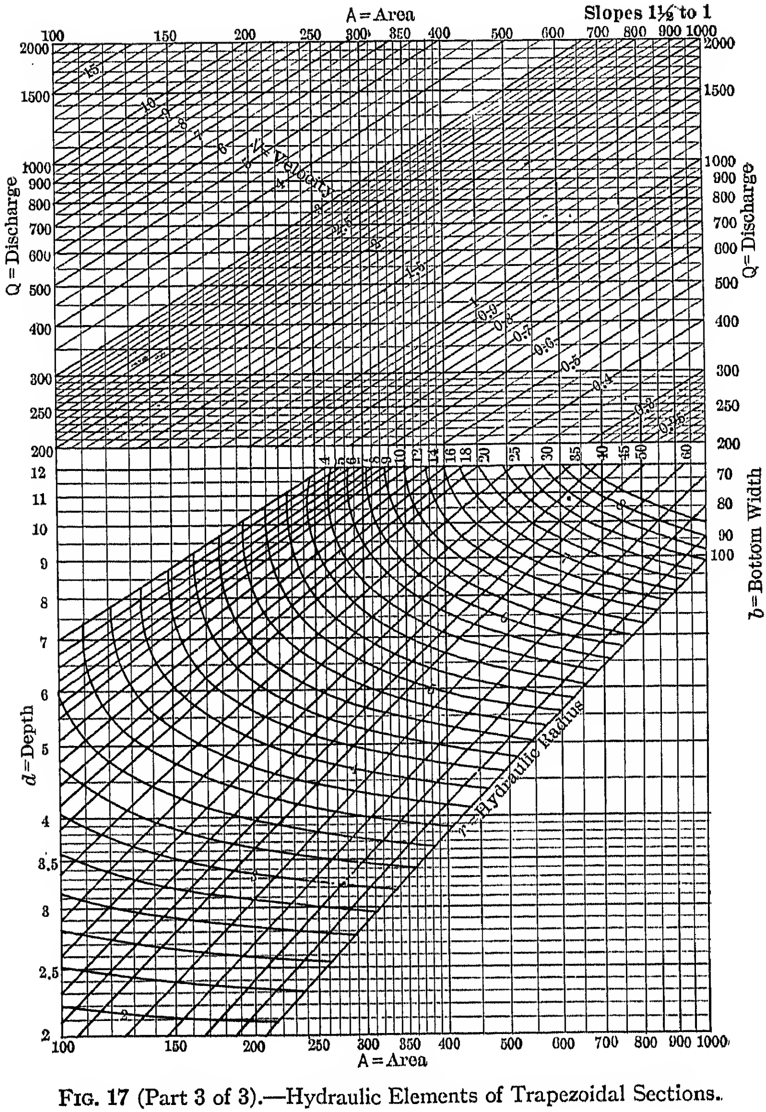


FIG. 17 (Part 3 of 3).—Hydraulic Elements of Trapezoidal Sections.

Formulæ:

$$A = b\,d + 2\,d^2$$

$$P = b + 4.48\,d$$

$$r = \frac{A}{P} = \frac{b\,d + 2\,d^2}{b + 4.48\,d}$$

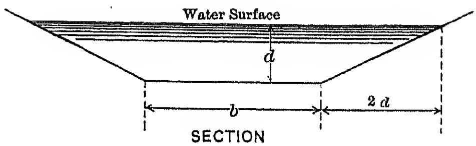
$$Q = A\,V$$

Problem:

$A = 7.2$

$r = 0.75$

Find b and d.



Solution:

Enter the diagram at $A = 7.2$, follow vertically to $r = 0.75$ (approximately half-way between $r = 0.7$ and $r = 0.8$), and read $b = 5$ and $d = 1.02$.

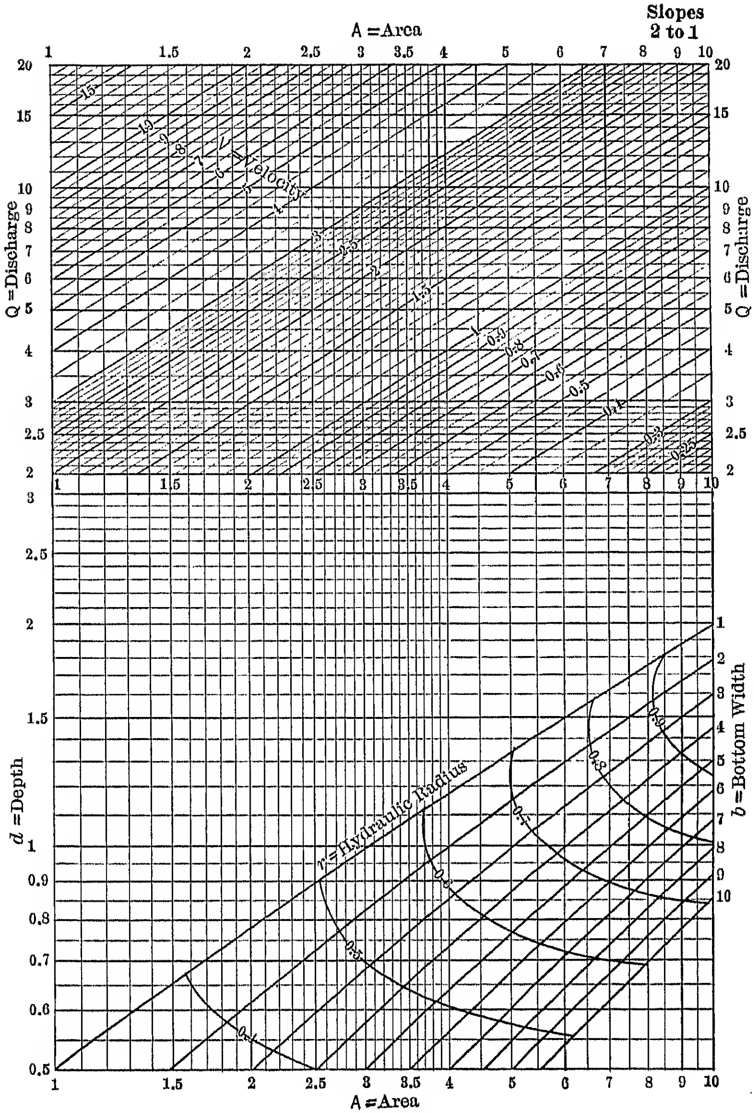


FIG. 18 (Part 1 of 3).—Hydraulic Elements of Trapezoidal Sections.

Formulæ:

$$A = b\,d + 2\,d^2$$

$$P = b + 4.48\,d$$

$$r = \frac{A}{P} = \frac{b\,d + 2\,d^2}{b + 4.48\,d}$$

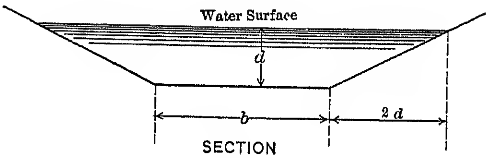
$$Q = A\,V$$

Problem:

$Q = 56$

$A = 44$

$d = 2.75$



Find V, b, and r.

Solution:

Enter the diagram at $Q = 56$; follow horizontally to $A = 44$ and read $V = 1.27$; thence vertically downward to $d = 2.75$, and read $b = 10.5$ and $r = 1.93$.

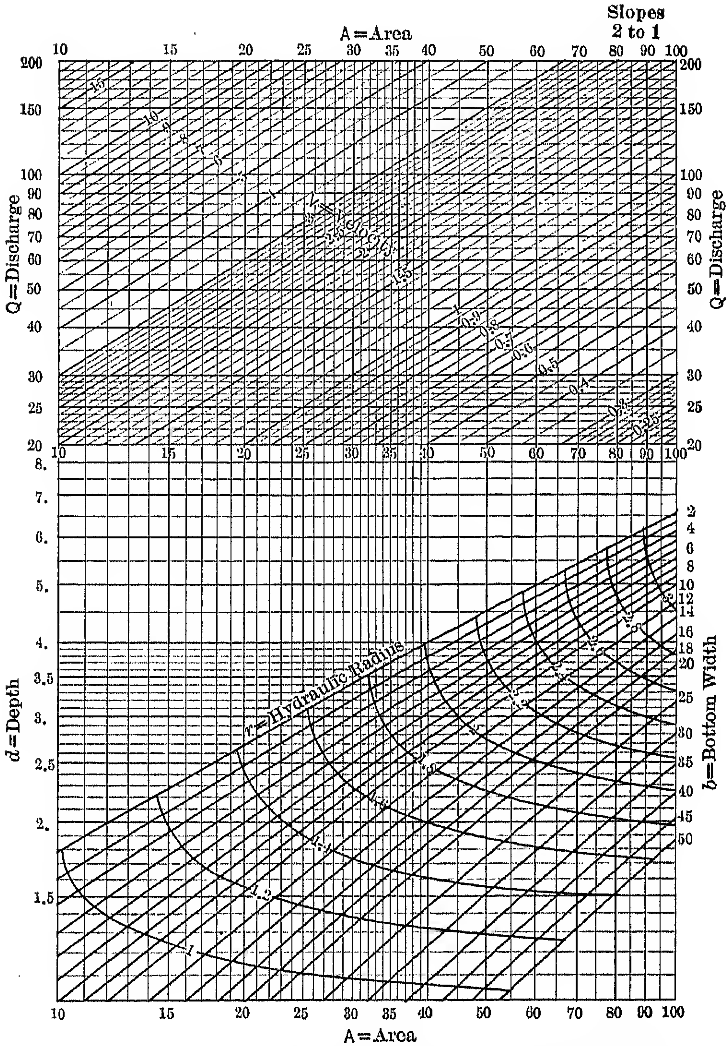


FIG. 18 (Part 2 of 3).—Hydraulic Elements of Trapezoidal Sections.

Formulæ:

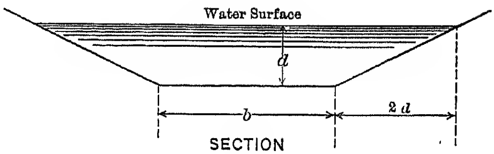
$$A = b\,d + 2\,d^2$$

$$P = b + 4.48\,d$$

$$r = \frac{A}{P} = \frac{b\,d + 2\,d^2}{b + 4.48\,d}$$

$$Q = A\,V$$

Problem:



$A = 640$

$r = 6.6$

$Q = 1440$

Find b, d, and V.

Solution:

Enter the diagram at $A = 640$; follow vertically to $r = 6.6$ and read $b = 60$ and $d = 8.4$; thence vertically upward to $Q = 1440$, and read $V = 2.25$.

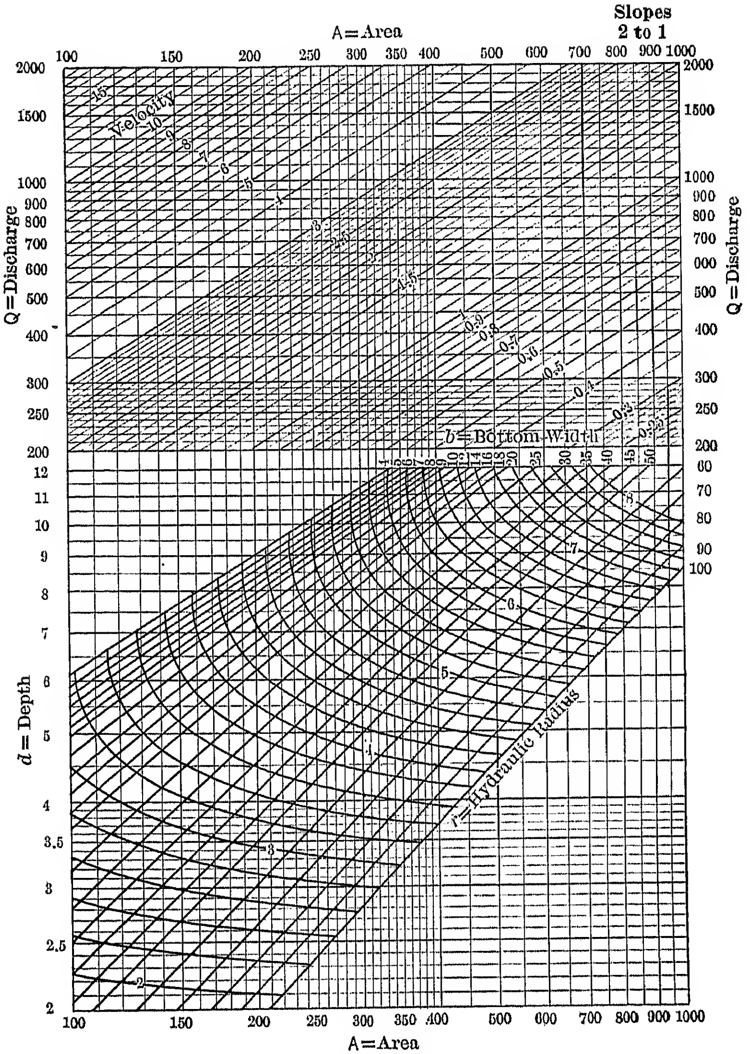


FIG. 18 (Part 3 of 3).—Hydraulic Elements of Trapezoidal Sections.

Formulæ:

$$A = b\,d + 1.25\,d^2$$
$$P = b + 3.22\,d$$
$$r = \frac{A}{P} = \frac{b\,d + 1.25\,d^2}{b + 3.22\,d}$$
$$Q = A\,V$$

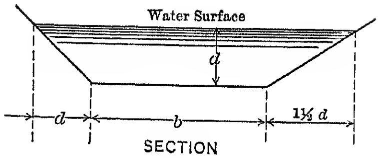
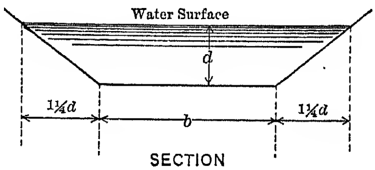


Fig. 19 may also be used for canal sections having both side slopes $1\frac{1}{4}$ to 1. The equations are:

$$A = b\,d + 1.25\,d^2$$
$$P = b + 3.20\,d$$
$$r = \frac{A}{P} = \frac{b\,d + 1.25\,d^2}{b + 3.20\,d}$$
$$Q = A\,V$$



It will be noted that the area is exactly the same as for the mixed slope section above, but the wetted perimeter, and consequently the hydraulic radius, is slightly different. The difference is, however, entirely insignificant for any practical canal section.

NOTE.—Mixed slopes are seldom used except for relatively large canals on steep side hills where steeper slopes are necessary on the upper side to reduce excavation. The hydraulic elements of smaller canals than those having a water area of 100 square feet have, therefore, not been plotted.

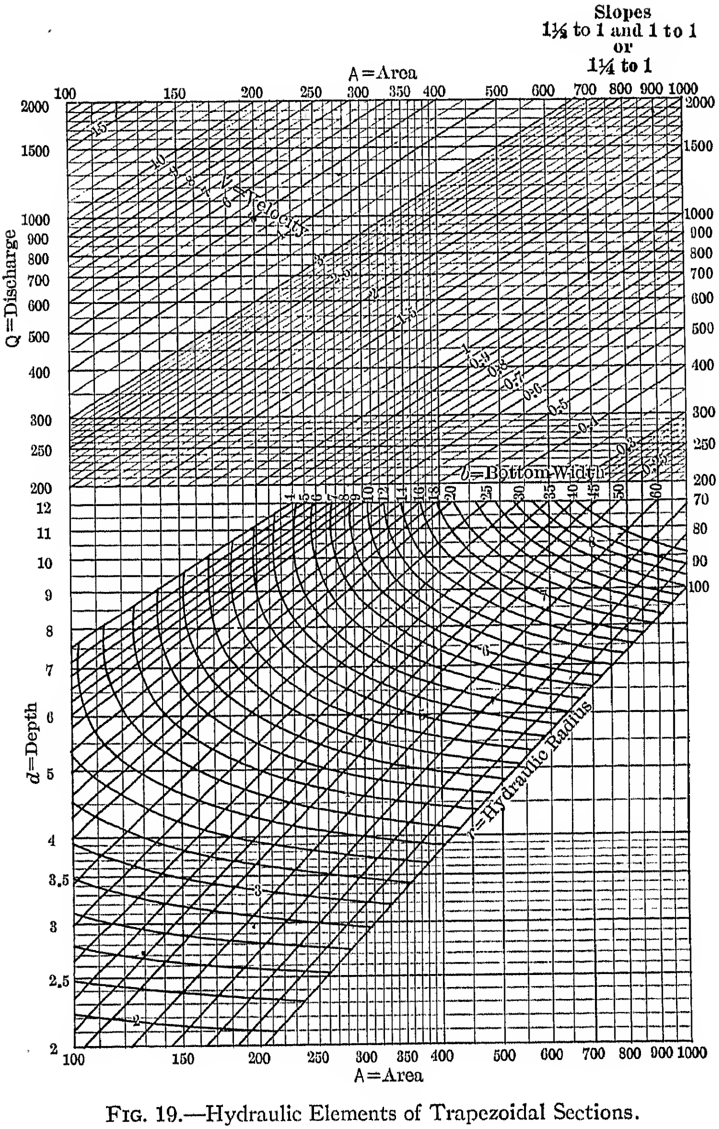


FIG. 19.—Hydraulic Elements of Trapezoidal Sections.

Formulæ:

$$A = b\,d + 1.75\,d^2$$
$$P = b + 4.04\,d$$
$$r = \frac{A}{P} = \frac{b\,d + 1.75\,d^2}{b + 4.04\,d}$$
$$Q = A\,V$$

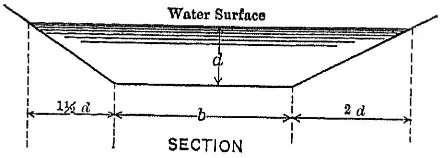
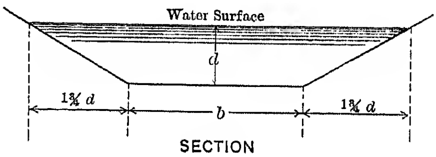


Fig. 20 may also be used for canal sections having both side slopes $1\frac{3}{4}$ to 1. The equations are:

$$A = b\,d + 1.75\,d^2$$
$$P = b + 4.03\,d$$
$$r = \frac{A}{P} = \frac{b\,d + 1.75\,d^2}{b + 4.03\,d^2}$$
$$Q = A\,V$$



It will be noted that the area is exactly the same as for the mixed slope section above, but the wetted perimeter, and consequently the hydraulic radius, is slightly different. The difference is, however, entirely insignificant for any practical canal section.

NOTE.—Mixed slopes are seldom used except for relatively large canals on steep side hills where steeper slopes are necessary on the upper side to reduce excavation. The hydraulic elements of smaller canals than those having a water area of 100 square feet have, therefore, not been plotted.

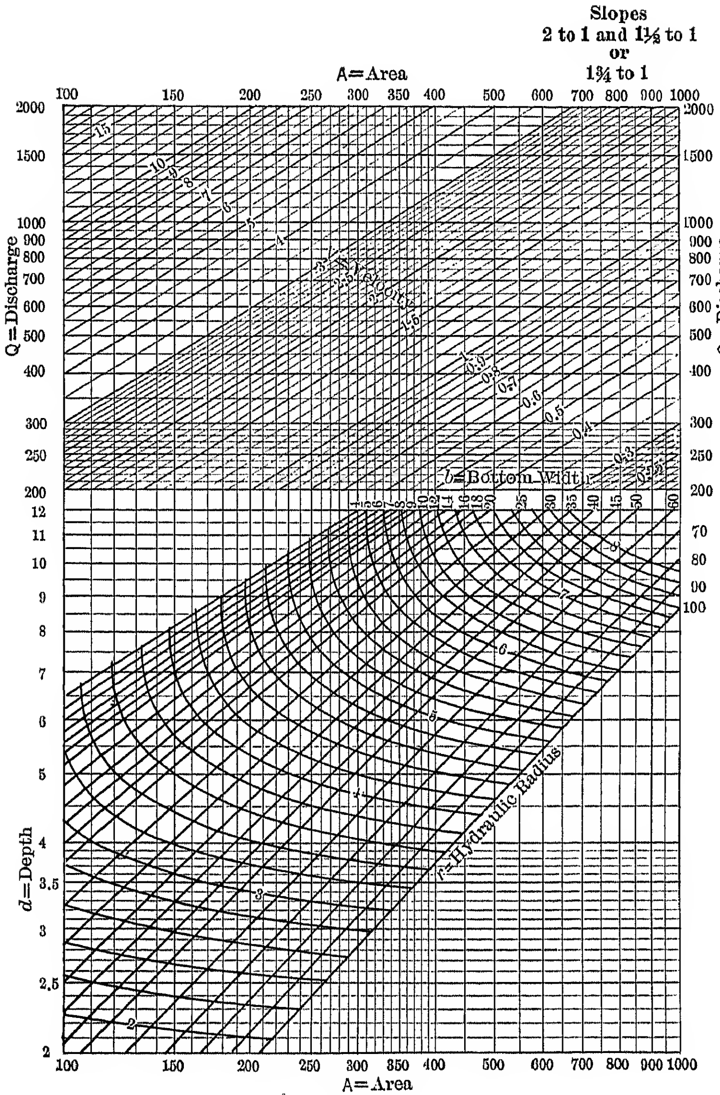
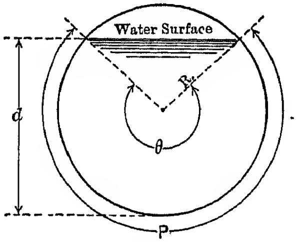
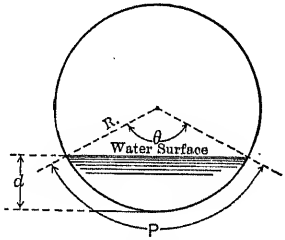


FIG. 20.—Hydraulic Elements of Trapezoidal Sections.



Case I
Segment larger than semicircle.



Case II
Segment smaller than semicircle.

Formulæ:

Full circle. $A = \pi R^2$

$$P = 2 \pi R$$

$$r = \frac{A}{P} = \frac{\pi R^2}{2 \pi R} = \frac{R}{2}$$

Segment. $A = \pi R^2 \frac{\theta}{360} - \frac{1}{2} R^2 \sin \theta$

$$P = 2 \pi R \frac{\theta}{360}$$

$$r = \frac{A}{P} = \frac{R}{2} - \frac{90 R \sin \theta}{\pi \theta}$$

These equations apply to both Case I and Case II, provided the proper sign is given to $\sin \theta$. For angles θ less than 180 degrees the second member of the equations for A and r is negative and must be subtracted. For angles θ greater than 180 degrees the second member of the equations is positive and must be added.

The hydraulic elements of segments having areas from 0.2 to 100 square feet are given in Fig. 21. For values not obtainable from the diagram the table on the next page or the fundamental equations above may be used.

Illustrations of use of Fig. 21.

1. Example.—A circular pipe having a radius of 2 feet has a depth of water of 0.95 foot. What are the area of water section and hydraulic radius?

Solution.—Enter the diagram at $d = 0.95$; follow vertically to the intersection with $R = 2$, and read $A = 2.28$ and $r = 0.56$.

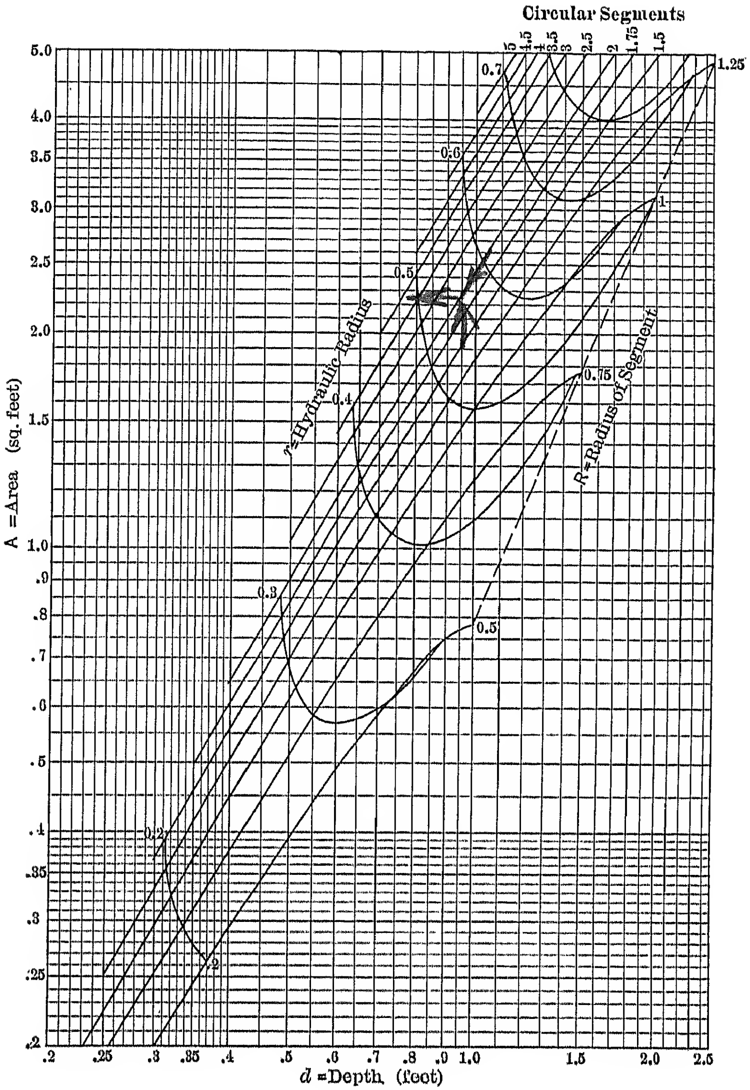


Fig. 21 (Part 1 of 2).—Hydraulic Elements of Circular Segments.

HYDRAULIC ELEMENTS OF CIRCULAR SEGMENTS. ALL VALUES ARE GIVEN IN TERMS OF THE RADIUS R

Depth	Area	Wetted Perimeter	Hydraulic Radius
0.1R	$.0588R^2$	0.902R	.0652R
0.2R	$.163R^2$	1.285R	.1268R
0.3R	$.294R^2$	1.586R	.1852R
0.4R	$.448R^2$	1.854R	.2415R
0.5R	$.614R^2$	2.09R	.293R
0.6R	$.792R^2$	2.32R	.341R
0.7R	$.979R^2$	2.53R	.386R
0.8R	$1.175R^2$	2.74R	.429R
0.9R	$1.370R^2$	2.94R	.466R
R	$1.57R^2$	3.14R	.500R
1.1R	$1.77R^2$	3.34R	.530R
1.2R	$1.965R^2$	3.54R	.555R
1.3R	$2.161R^2$	3.75R	.576R
1.4R	$2.348R^2$	3.94R	.596R
1.5R	$2.526R^2$	4.19R	.603R
1.6R	$2.692R^2$	4.43R	.608R
1.7R	$2.846R^2$	4.69R	.607R
1.8R	$2.977R^2$	5.00R	.595R
1.9R	$3.081R^2$	5.38R	.565R
2R	$3.142R^2$	6.28R	.500R

NOTE.—This table is intended for use in calculating the hydraulic elements of circular segments having an area greater than 100 square feet, which is the limit of the diagram. It has, however, general application and may be used for calculating any circular segment.

2. Example.—What are the hydraulic radius and depth of flow of a pipe of 6 feet radius when the area is 75 square feet?

Solution.—Enter the diagram at $A = 75$; follow horizontally to the line representing $R = 6$, and read $d = 7.55$ and $r = 3.4$.

3. Example.—For an area of 25 square feet what radius of pipe will give the greatest hydraulic radius?

Solution.—Enter the diagram at $A = 25$; follow horizontally to the point indicating the greatest hydraulic radius, which is when $R = 4$ feet.

4. Example.—The area of a segment is 30 square feet and the depth of flow is 4 feet. What are the radius of segment and hydraulic radius?

Solution.—Enter the diagram at $A = 30$; follow horizontally to the vertical line representing $d = 4$, and read by interpolation $R = 5.8$, also $r = 2.15$.

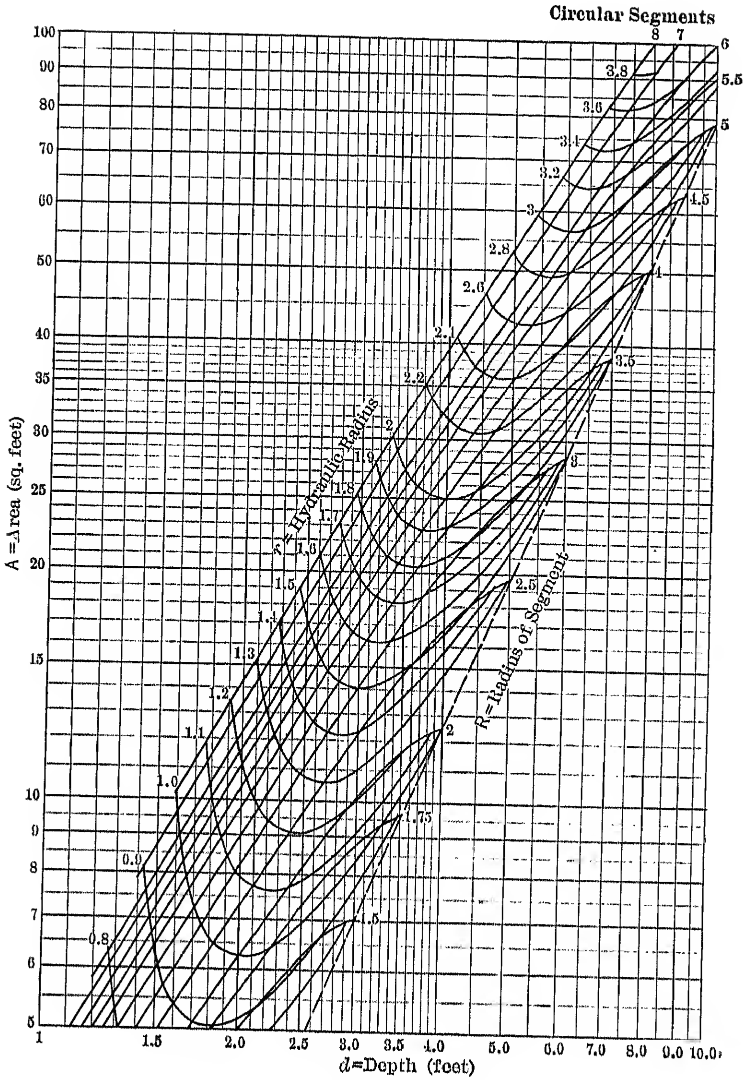


FIG. 21 (Part 2 of 2).—Hydraulic Elements of Circular Segments.

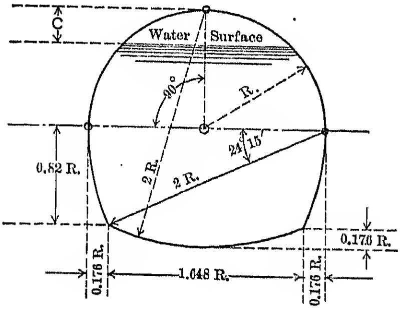
Horseshoe Sections

Sections having the upper portion in the form of a semicircle and the lower portion composed of arcs of larger radius, or of straight lines, are commonly called "horseshoe" sections. They are frequently used for tunnels in yielding material and for outlet conduits under earth dams.

The horseshoe section has some hydraulic and structural advantages over circular and other sections. The hydraulic value of the section illustrated on the opposite page, for a depth of flow of 1.6 R (or clearance $C = 0.4\,R$), may be seen by comparing the area and hydraulic radius of this section for this condition with the same elements for a circular section as given in the table on page 146. The areas are seen to be 2.85 R^2 and 2.692 R^2 respectively, and the hydraulic radii 0.610 R and 0.608 R respectively. Structurally the horseshoe section affords more floor room and permits the building of the sides and arch of the lining before the invert is put in—important factors in tunnel work.

It is said that the most favorable section of the horseshoe type is when the total height is equal to the greatest width, as in the section illustrated on page 149. The calculation of the hydraulic elements of such sections is a tedious process and much labor may be saved by the use of the table on the opposite page. Slight deviations from the given section, such as making the sides below the center line straight and the bottom of two straight lines, will still allow the use of this table for preliminary calculations on which to base the size of the section. After the size and form have been decided upon, more exact calculations of the hydraulic elements can be made if desired.

Hydraulic Elements of a Horseshoe Section



All values are given in terms of R

Clearance C	Area	Wetted Perimeter	Hydraulic Radius
0	$3.30R^2$	6.52R	0.506R
0.1R	$3.24R^2$	5.62R	0.576R
0.2R	$3.13R^2$	5.24R	0.598R
0.3R	$3.01R^2$	4.93R	0.610R
0.4R	$2.85R^2$	4.67R	0.610R
0.5R	$2.69R^2$	4.43R	0.607R
0.6R	$2.51R^2$	4.18R	0.600R
0.7R	$2.32R^2$	3.99R	0.582R
0.8R	$2.12R^2$	3.78R	0.561R
0.9R	$1.93R^2$	3.58R	0.539R
R	$1.73R^2$	3.38R	0.512R

Example 1.—The section has a radius R of 5 feet. The surface of the water is one foot below the top. What are the area and hydraulic radius?

$$\text{Clearance } C = 1/5\ R = 0.2\ R$$
$$\text{Area} = 3.13\ R^2 = 78.2 \text{ sq. ft.}$$
$$\text{Hydraulic radius} = .598\ R = 2.99 \text{ feet}$$

Example 2.—The required area of water section is 125 square feet and the clearance of water surface below top shall be 0.3 R. What is the radius?

$$\text{Area} = 3.01\ R^2 = 125$$
$$\therefore R = 6.45 \text{ feet}$$
$$\text{Hydraulic radius} = 0.61\ R = 3.93 \text{ feet}$$
$$\text{Clearance } C = 6.45 \times 0.3 = 1.94 \text{ feet}$$

TABLE 22

Circular Conduits Flowing Partly Full

(Kutter Formula)

Values by which discharge and velocity of a circular conduit flowing full should be multiplied to obtain the discharge and velocity of the same conduit with the proportionate depth on invert given in the first column. For use with Fig. 22. D = diameter of conduit.

$$\text{Proportionate depth} = \frac{\text{Depth of flow}}{D}$$

Proportionate Depth	D = 1 Ft.		D = 2 Ft.		D = 4 Ft.		D = 6 Ft.		D = 10 Ft.	
	Velocity	Discharge	V	Q	V	Q	V	Q	V	Q
.10	.333	.0174	.351	.0183	.370	.0193	.379	.0198	.388	.0202
.11	.359	.0216	.377	.0226	.396	.0237	.405	.0242	.414	.0247
.12	.385	.0262	.403	.0274	.421	.0286	.430	.0292	.438	.0298
.13	.410	.0313	.428	.0327	.446	.0340	.454	.0346	.461	.0352
.14	.433	.0369	.452	.0385	.469	.0399	.477	.0406	.484	.0412
.15	.456	.0429	.475	.0447	.492	.0463	.500	.0470	.507	.0477
.16	.478	.0494	.497	.0513	.514	.0531	.522	.0539	.529	.0547
.17	.501	.0564	.518	.0583	.535	.0604	.544	.0613	.551	.0621
.18	.523	.0640	.539	.0660	.557	.0682	.565	.0691	.572	.0700
.19	.544	.0720	.560	.0742	.578	.0764	.586	.0775	.592	.0784
.20	.565	.0804	.581	.0827	.598	.0851	.606	.0863	.612	.0871
.21	.585	.0892	.601	.0916	.617	.0942	.625	.0955	.631	.0963
.22	.604	.0985	.620	.101	.635	.104	.643	.105	.649	.106
.23	.623	.108	.638	.111	.653	.114	.660	.115	.666	.116
.24	.642	.118	.656	.121	.670	.124	.677	.126	.683	.126
.25	.660	.129	.674	.132	.687	.134	.694	.136	.700	.137
.26	.677	.140	.691	.143	.704	.145	.711	.147	.716	.148
.27	.695	.152	.708	.154	.720	.157	.727	.159	.732	.159
.28	.713	.164	.725	.166	.736	.169	.743	.171	.748	.171
.29	.729	.176	.741	.178	.752	.181	.758	.183	.763	.183
.30	.745	.188	.756	.191	.768	.194	.773	.195	.778	.196
.31	.760	.201	.771	.204	.782	.207	.787	.208	.792	.209
.32	.776	.214	.785	.217	.796	.220	.801	.221	.806	.222
.33	.791	.228	.800	.231	.810	.233	.815	.234	.819	.235
.34	.806	.242	.815	.245	.824	.247	.828	.248	.832	.249
.35	.821	.257	.830	.259	.837	.261	.841	.262	.844	.263
.36	.835	.271	.843	.274	.850	.275	.854	.276	.857	.277
.37	.848	.286	.856	.289	.863	.290	.866	.291	.869	.292
.38	.862	.301	.869	.304	.875	.305	.878	.306	.881	.307
.39	.875	.316	.882	.319	.887	.320	.890	.321	.893	.322
.40	.888	.332	.894	.334	.899	.336	.901	.337	.905	.338
.41	.900	.348	.906	.349	.910	.351	.912	.352	.916	.353
.42	.912	.364	.917	.365	.921	.367	.923	.368	.927	.369
.43	.924	.380	.929	.381	.932	.383	.934	.384	.936	.385
.44	.936	.397	.940	.398	.943	.399	.944	.400	.945	.401
.45	.948	.414	.951	.415	.953	.416	.954	.416	.955	.417
.46	.960	.431	.961	.432	.963	.433	.964	.433	.965	.434
.47	.970	.448	.971	.449	.973	.450	.973	.450	.974	.451
.48	.980	.465	.981	.466	.982	.466	.982	.466	.983	.467
.49	.990	.482	.991	.483	.991	.483	.991	.483	.992	.483
.50	1.000	.500	1.000	.500	1.000	.500	1.000	.500	1.000	.500
.51	1.009	.517	1.009	.517	1.009	.517	1.009	.517	1.008	.517
.52	1.018	.535	1.018	.534	1.017	.534	1.017	.534	1.016	.533
.53	1.027	.553	1.026	.552	1.025	.551	1.025	.551	1.023	.550
.54	1.036	.571	1.035	.570	1.033	.568	1.033	.568	1.030	.567
.55	1.045	.589	1.043	.588	1.040	.586	1.040	.586	1.037	.584

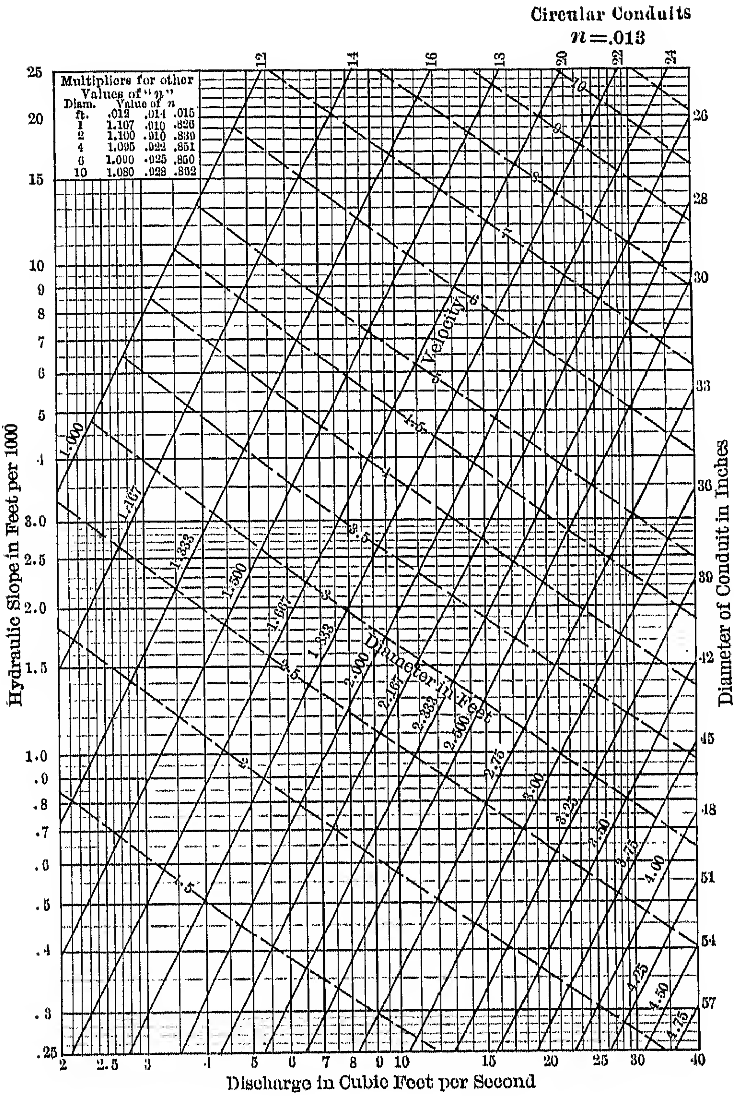


FIG. 22 (Part 1 of 2).—Discharge of Circular Conduits Flowing Full by Kutter Formula.

(Explanation page 78.)

TABLE 22 (*Concluded*)

CIRCULAR CONDUITS FLOWING PARTLY FULL

Propor-tionate Depth	D = 1 Ft.		D = 2 Ft.		D = 4 Ft.		D = 6 Ft.		D = 10 Ft.	
	Velo-city	Dis-charge	V	Q	V	Q	V	Q	V	Q
.56	1.053	.607	1.051	.606	1.047	.604	1.047	.603	1.044	.602
.57	1.061	.625	1.058	.624	1.054	.622	1.054	.620	1.051	.619
.58	1.069	.643	1.065	.642	1.061	.639	1.060	.637	1.057	.636
.59	1.076	.660	1.072	.659	1.068	.656	1.068	.654	1.063	.653
.60	1.083	.678	1.078	.676	1.074	.673	1.072	.671	1.069	.670
.61	1.089	.696	1.084	.694	1.080	.690	1.078	.689	1.075	.687
.62	1.095	.714	1.090	.711	1.086	.707	1.084	.706	1.081	.704
.63	1.101	.732	1.096	.728	1.092	.724	1.090	.723	1.087	.721
.64	1.107	.749	1.102	.745	1.097	.741	1.095	.740	1.092	.738
.65	1.113	.766	1.107	.762	1.102	.758	1.100	.757	1.097	.755
.66	1.117	.783	1.112	.779	1.107	.775	1.105	.773	1.101	.771
.67	1.123	.800	1.117	.796	1.111	.791	1.109	.789	1.105	.787
.68	1.129	.817	1.122	.813	1.115	.807	1.113	.805	1.109	.803
.69	1.133	.834	1.126	.829	1.119	.823	1.116	.821	1.113	.819
.70	1.137	.851	1.130	.845	1.122	.839	1.119	.837	1.117	.835
.71	1.141	.867	1.134	.860	1.126	.854	1.123	.852	1.120	.850
.72	1.145	.883	1.137	.875	1.129	.869	1.126	.867	1.123	.865
.73	1.148	.898	1.140	.890	1.132	.884	1.129	.882	1.125	.880
.74	1.150	.913	1.142	.905	1.134	.899	1.131	.897	1.127	.894
.75	1.152	.928	1.144	.920	1.136	.914	1.133	.911	1.129	.908
.76	1.154	.942	1.146	.934	1.138	.928	1.135	.925	1.131	.922
.77	1.156	.956	1.148	.948	1.140	.942	1.136	.939	1.133	.936
.78	1.157	.969	1.149	.962	1.141	.955	1.137	.952	1.134	.949
.79	1.159	.982	1.150	.975	1.142	.968	1.138	.965	1.135	.962
.80	1.160	.994	1.151	.987	1.143	.980	1.139	.977	1.136	.974
.81	1.161	1.006	1.152	.999	1.144	.992	1.140	.989	1.137	.972
.82	1.161	1.017	1.152	1.010	1.144	1.004	1.140	1.000	1.137	.996
.83	1.160	1.028	1.151	1.021	1.143	1.015	1.139	1.011	1.136	1.007
.84	1.159	1.038	1.150	1.031	1.142	1.025	1.138	1.021	1.135	1.017
.85	1.157	1.048	1.148	1.041	1.141	1.034	1.137	1.030	1.134	1.027
.86	1.155	1.057	1.146	1.050	1.139	1.042	1.135	1.038	1.132	1.035
.87	1.152	1.065	1.144	1.058	1.137	1.050	1.133	1.046	1.130	1.043
.88	1.149	1.071	1.141	1.064	1.134	1.057	1.130	1.053	1.127	1.050
.89	1.146	1.077	1.138	1.070	1.131	1.063	1.127	1.059	1.124	1.057
.90	1.142	1.082	1.134	1.075	1.127	1.068	1.123	1.065	1.121	1.063
.91	1.137	1.086	1.130	1.079	1.123	1.072	1.119	1.069	1.117	1.067
.92	1.132	1.090	1.125	1.083	1.118	1.076	1.114	1.072	1.112	1.070
.93	1.125	1.091	1.119	1.085	1.112	1.078	1.109	1.075	1.107	1.073
.94	1.118	1.091	1.112	1.085	1.105	1.078	1.102	1.075	1.100	1.073
.95	1.109	1.088	1.103	1.082	1.097	1.076	1.095	1.074	1.093	1.072
1.00	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

NOTE.—For any diameter greater than 10 feet that is likely to be used in practice the multipliers are practically the same as for the 10 feet diameter.

There is a slight variation with the slope that is not accounted for in the above table. For slopes greater than .0005 the error of the table from this source is usually less than one per cent. For flatter slopes the error is somewhat greater.

This table is adapted from tables in Garrett's "Hydraulic Diagrams for Practical Engineers."

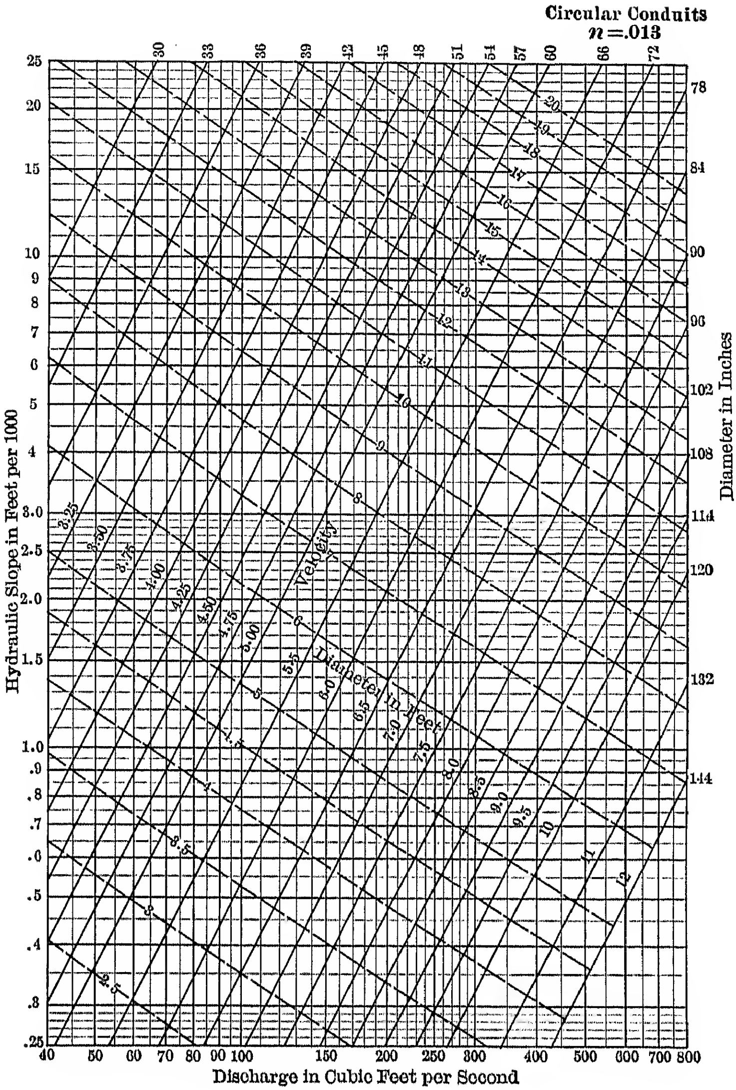


FIG. 22 (Part 2 of 2).—Discharge of Circular Conduits Flowing Full by Kutter Formula.

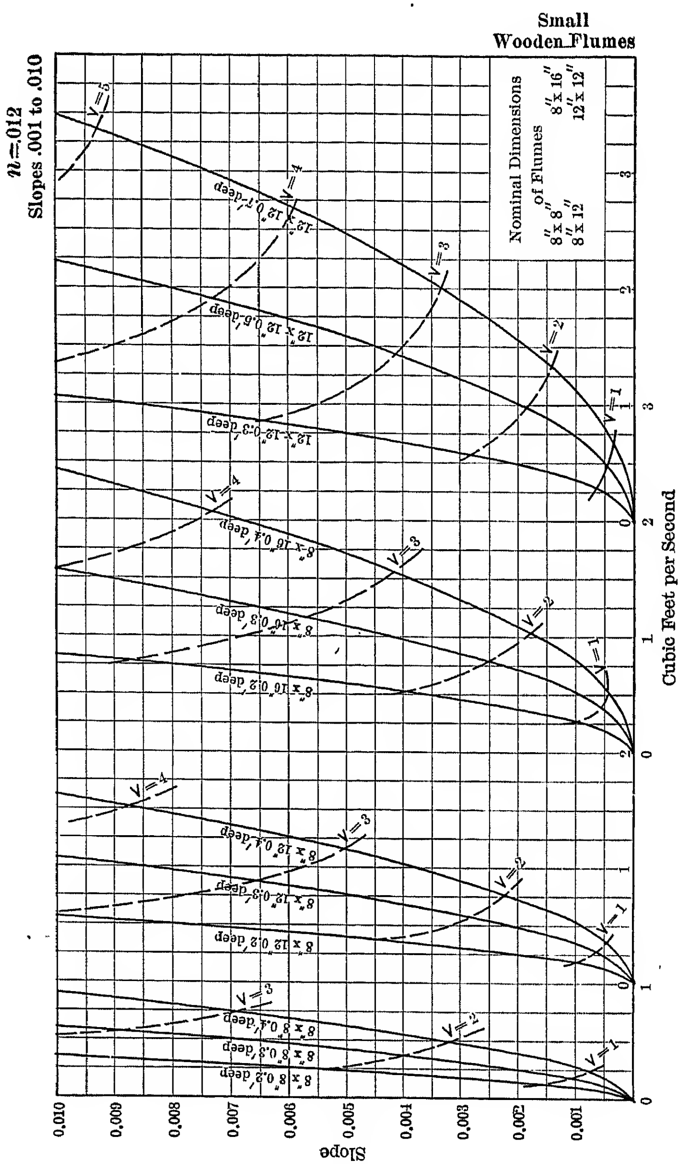


FIG. 23 (Part 1 of 3).—Discharge of Rectangular Wooden Flumes.

(Explanation page 80.)

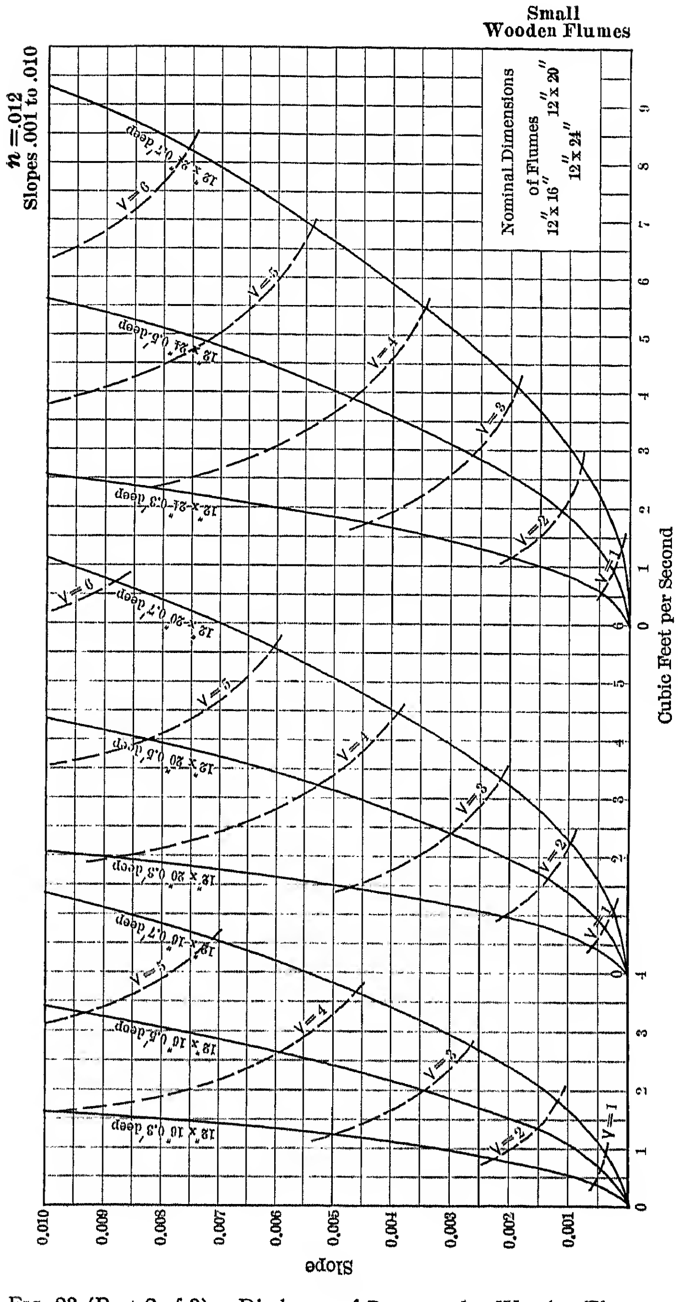


Fig. 23 (Part 2 of 3).—Discharge of Rectangular Wooden Flumes.

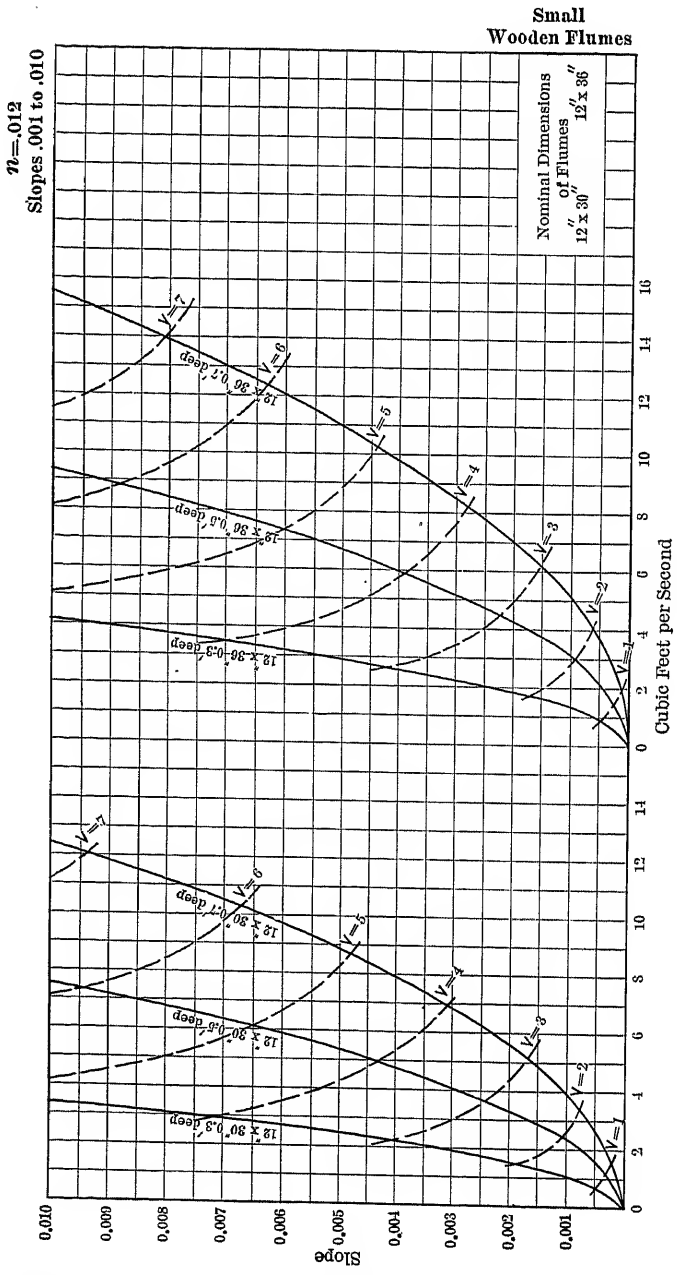


FIG. 23 (Part 3 of 3).—Discharge of Rectangular Wooden Flumes.

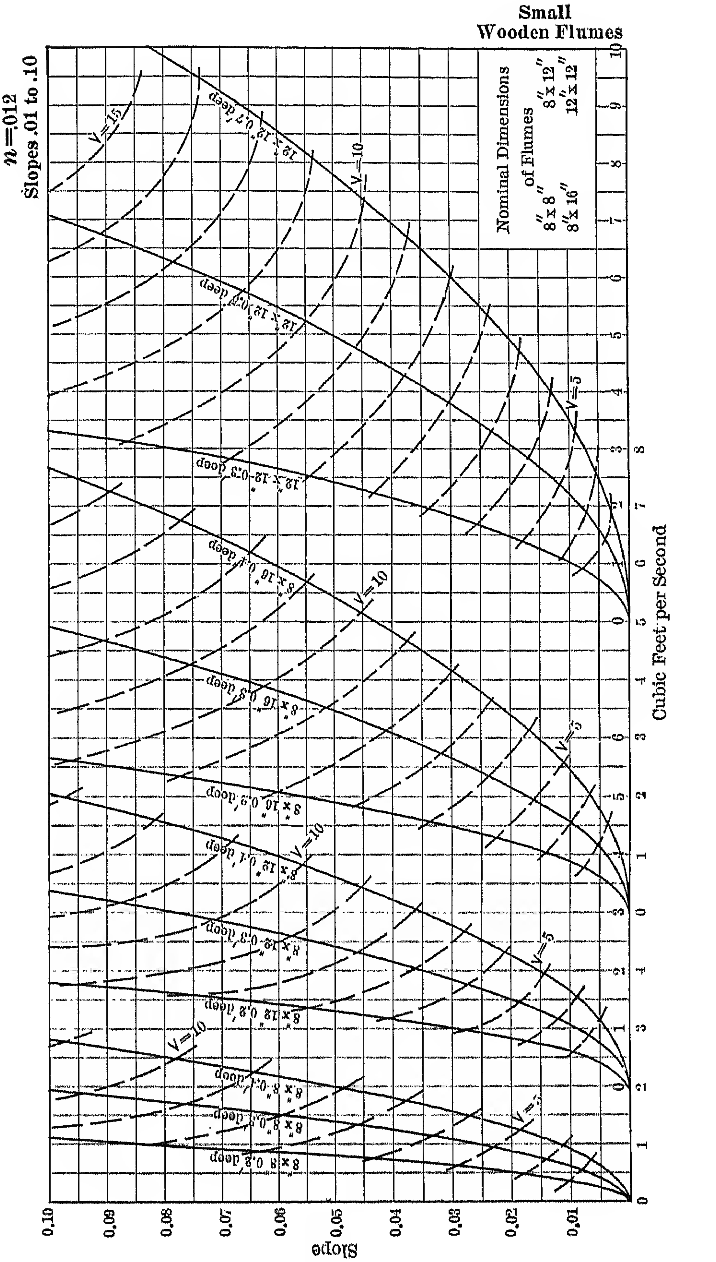


FIG. 24 (Part 1 of 3).—Discharge of Rectangular Wooden Flumes.
(Explanation page 80.)

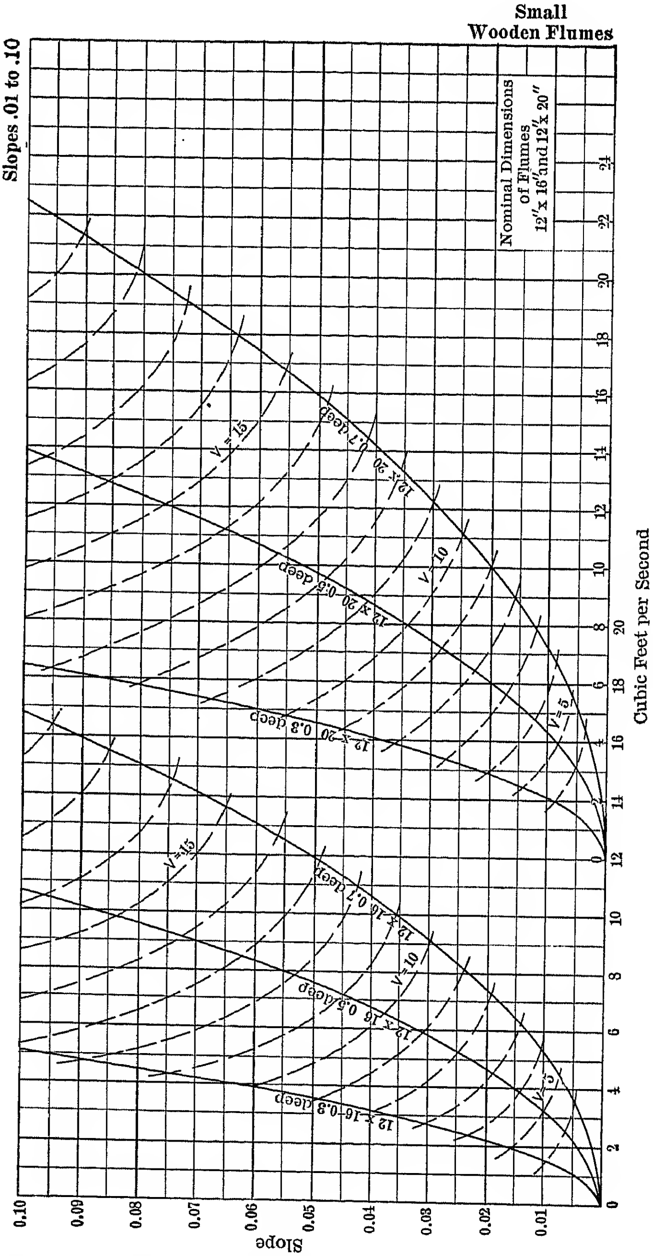


FIG. 24 (Part 2 of 3).—Discharge of Rectangular Wooden Flumes.

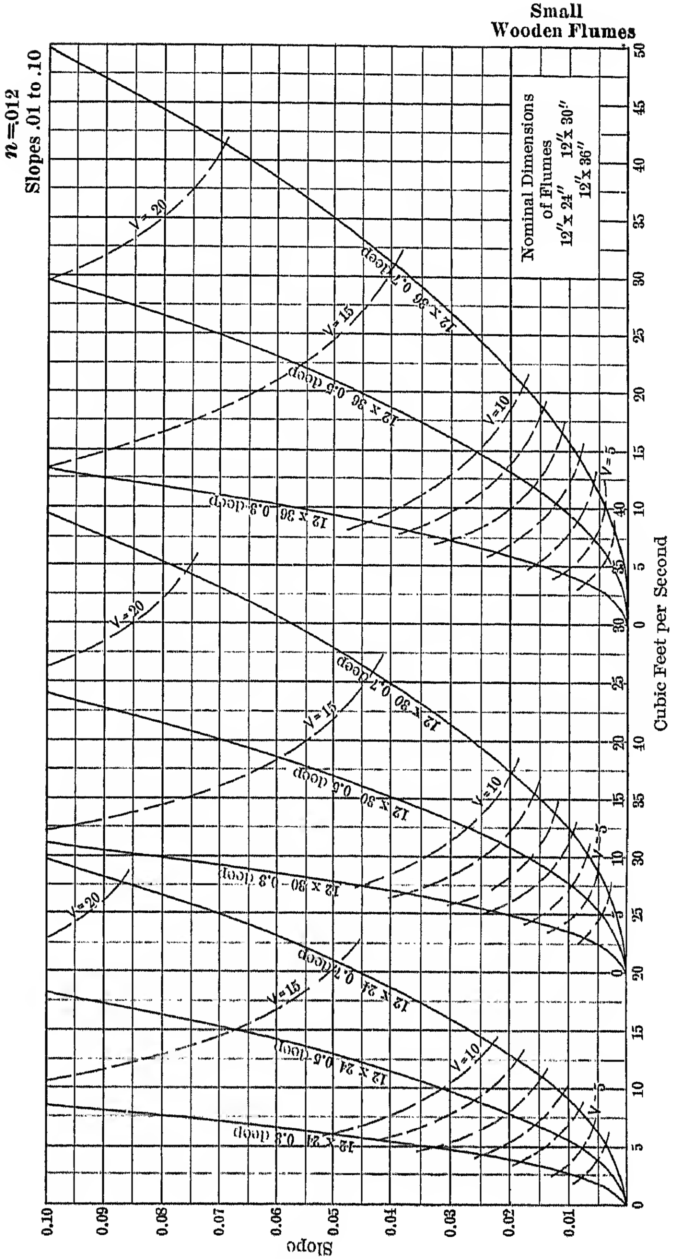


FIG. 24 (Part 3 of 3).—Discharge of Rectangular Wooden Flumes.

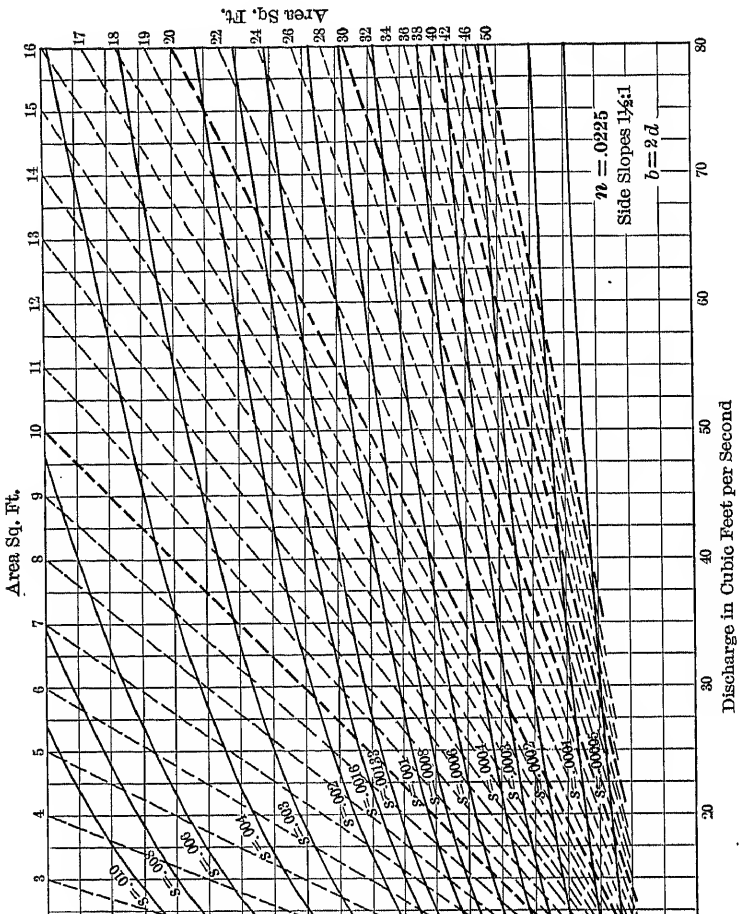


FIG. 25.—Hydraulic Curves for Small Canals.

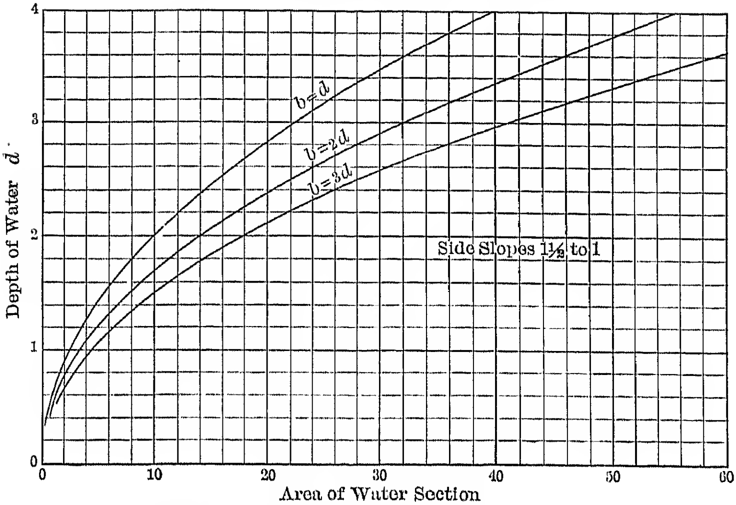


FIG. 25½.—Curves for Proportioning the Section.

Use of Figs. 25 to 28

1. Problem:

What slope of water surface is required for a canal to have a discharge of 60 c. f. s., a mean velocity of 2.2 feet per second, 1½ to 1 side slopes, and a ratio of bottom width to depth of 2 to 1? $n = .0225$. Also find the required bottom width and depth.

Solution:

In Fig. 25, at the intersection of the lines representing $Q = 60$ and $V = 2.2$ we read $S = .00058$. At the same time we read on the diagonal line the area of water section equals 27. To find the required bottom width and depth we now turn to Fig. 25½ and at the intersection with the imaginary line representing area = 27 and the line marked "$b = 2d$" we read $d = 2.7 +$; and b is therefore equal to 2.7×2 or 5.4 feet.

The hydraulic elements of the canal section then are:

$Q = 60$	$b = 5.4$
$V = 2.2$	$d = 2.7$
$S = .00058$	$n = .0225$

Side slopes 1½ to 1

If the canal were to have a ratio of bottom width to depth of 3, Fig. 25 would be used in the same manner as above, but in using Fig. 25½ the line marked "$b = 3d$" would be used and we would find $d = 2.45$ and $b = 2.45 \times 3 = 7.35$. The line marked "$b = d$" is used in a similar manner to proportion a section having this ratio. The other elements of the canal section would remain as above. The results in the latter cases would not be exact because Fig. 25 is based on a ratio of bottom width to depth of 2 to 1, but the error is not of practical significance for canals of the sizes considered.

For $n = .025$, Fig. 26, instead of Fig. 25, is used, but Fig. 25½ is used in the same manner as above outlined.

2. Problem:

What slope, bottom width, and depth are required for a canal to carry 5 c. f. s. if the velocity is to be 1.5 feet per second, side slopes 1½ to 1, ratio of bottom width to depth 2 to 1, and $n = .025$?

Solution:

In Fig. 28, at the intersection of the lines representing $Q = 5$, and $V = 1.5$, we read $S = .0016$, and interpolating between diagonal lines we find the area of water section to be 3.3 square feet. Turning now to Fig. 27½, we read at the intersection of the imaginary line representing area $= 3.3$ with the line marked "$b = 3d$" that $d = 0.85$ foot; hence $b = 3 \times 0.85 = 2.55$ feet.

The hydraulic elements of the canal section then are:

$Q = 5$
$V = 1.5$
$S = .0016$
$b = 2.55$
$d = 0.85$
$n = .025$
Side slopes 1½ to 1

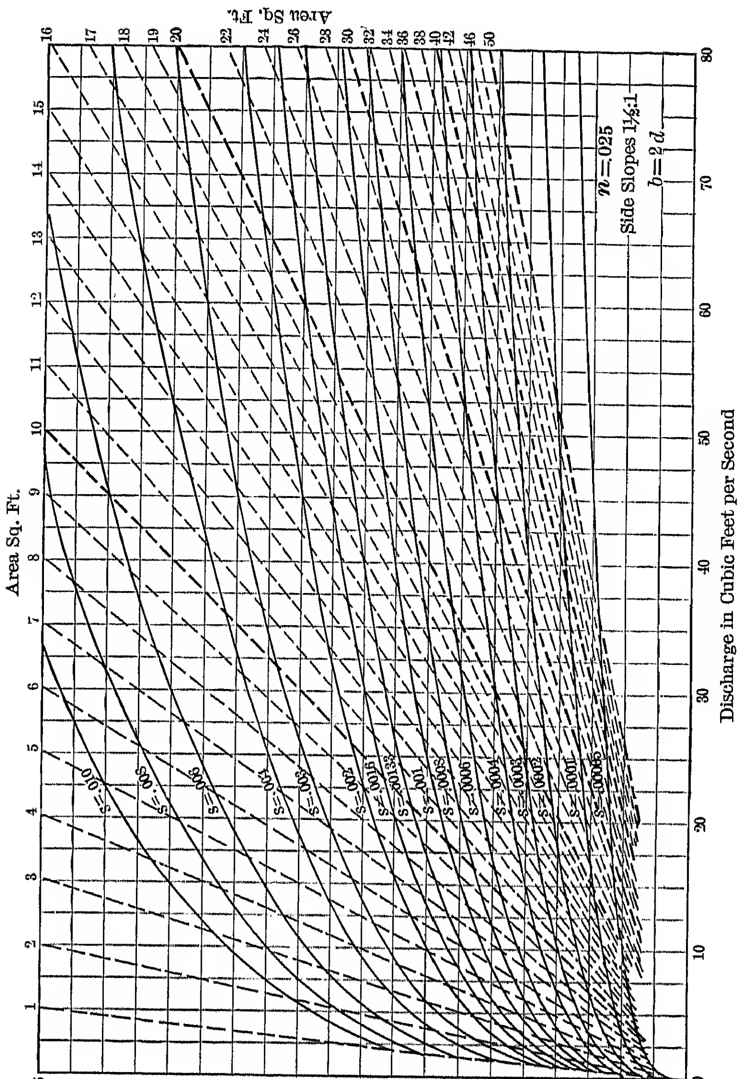


FIG. 26.—Hydraulic Curves for Small Canals.

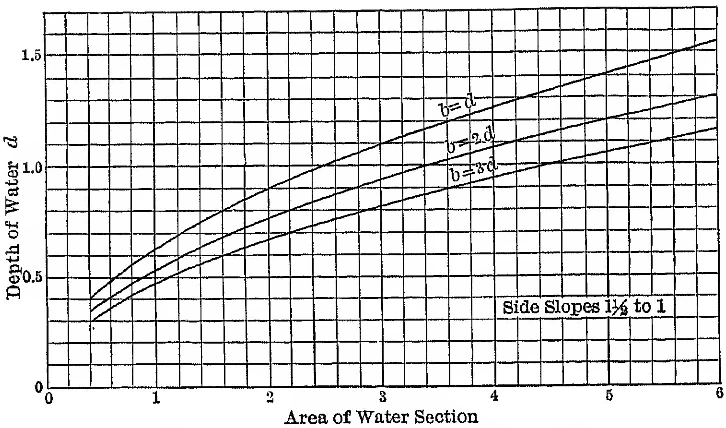


FIG. 27½.—Curves for Proportioning the Section.

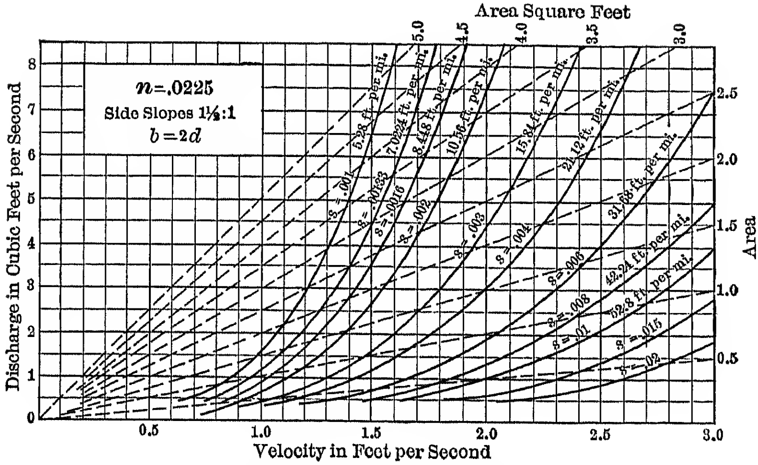


FIG. 27.—Hydraulic Curves for Small Laterals.

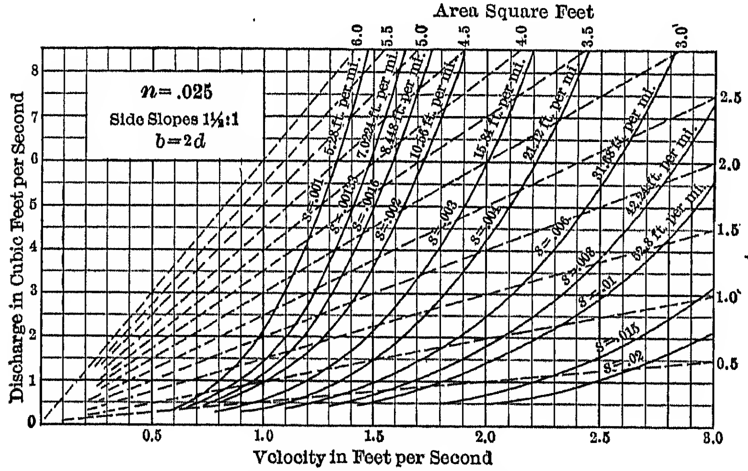


FIG. 28.—Hydraulic Curves for Small Laterals.

TABLE 23

Semicircular Steel Flumes

Freeboard, depth, and area for different conditions of flow, and multipliers for other values of n. For use with Fig. 29.

Trade Number	Diameter of Flume	Freeboard and Depth of Flow in Feet and Area in Square Feet								Multipliers for Other Values of n			Diameter of Flume in Feet
		Freeboard $R/6$ Depth of Flow .417 D Multiplier for V 1.00 Multiplier for Q 1.00		Freeboard $R/8$ Depth of Flow .437 D Multiplier for V 1.024 Multiplier for Q 1.083		Freeboard $R/10$ Depth of Flow .45 D Multiplier for V 1.039 Multiplier for Q 1.149		Freeboard $R/12$ Depth of Flow .458 D Multiplier for V 1.048 Multiplier for Q 1.187					
		Free-board	Depth & Area	Free-board	Depth & Area	Free-board	Depth & Area	Free-board	Depth & Area	n .013	n .014	n .015	
18	1′- 0″	0.083	0.417 0.31	0.062	0.437 0.33	0.050	0.450 0.34	0.042	0.458 0.35	.903	.822	.746	1.000
24	1′- 3¼″	0.106	0.530 0.50	0.080	0.556 0.54	0.064	0.572 0.55	0.053	0.582 0.57	.905	.826	.750	1.271
36	1′-11″	0.160	0.800 1.13	0.120	0.840 1.21	0.096	0.864 1.25	0.080	0.880 1.28	.908	.832	.762	1.920
48	2′- 6½″	0.212	1.06 2.01	0.159	1.11 2.15	0.127	1.14 2.22	0.106	1.17 2.27	.910	.836	.768	2.542
60	3′- 2¼″	0.265	1.33 3.13	0.199	1.40 3.35	0.159	1.44 3.46	0.132	1.46 3.54	.912	.839	.773	3.190
72	3′-10″	0.320	1.60 4.52	0.239	1.68 4.84	0.192	1.72 5.00	0.160	1.76 5.12	.913	.842	.777	3.833
84	4′- 5½″	0.371	1.86 6.16	0.278	1.95 6.60	0.223	2.01 6.81	0.186	2.04 6.97	.914	.844	.780	4.458
96	5′- 1″	0.423	2.12 8.03	0.317	2.22 8.60	0.254	2.29 8.87	0.212	2.33 9.10	.915	.846	.782	5.083
108	5′- 8¾″	0.477	2.39 10.17	0.358	2.51 10.90	0.286	2.58 11.2	0.238	2.63 11.5	.916	.847	.784	5.729
120	6′- 4½″	0.530	2.66 12.53	0.398	2.79 13.40	0.318	2.87 13.8	0.265	2.92 14.2	.917	.848	.786	6.375
132	7′- 0″	0.583	2.92 15.18	0.437	3.06 16.2	0.350	3.15 16.8	0.292	3.21 17.2	.918	.849	.788	7.000
144	7′- 7¾″	0.637	3.19 18.10	0.478	3.35 19.4	0.382	3.44 20.0	0.318	3.51 20.5	.918	.850	.790	7.646
156	8′- 4″	0.695	3.47 21.55	0.520	3.65 23.1	0.417	3.75 23.8	0.348	3.82 24.4	.919	.851	.791	8.333
168	8′-11″	0.743	3.72 24.66	0.557	3.90 26.4	0.445	4.01 27.3	0.372	4.09 27.9	.919	.852	.792	8.920
180	9′- 6¾″	0.797	3.98 28.36	0.598	4.19 30.4	0.479	4.30 31.3	0.398	4.38 32.1	.919	.853	.793	9.562
192	10′- 2″	0.847	4.24 32.10	0.635	4.45 34.3	0.508	4.58 35.5	0.424	4.66 36.3	.920	.853	.793	10.167
204	10′-10″	0.903	4.51 36.36	0.677	4.74 38.9	0.542	4.87 40.2	0.452	4.97 41.2	.920	.854	.794	10.833
216	11′- 5½″	0.955	4.77 40.80	0.717	5.01 43.7	0.573	5.16 45.1	0.478	5.25 46.2	.920	.855	.795	11.458
228	12′- 1″	1.006	5.03 45.40	0.755	5.29 48.6	0.605	5.44 50.2	0.503	5.54 51.4	.921	.855	.796	12.083
240	12′- 8¾″	1.060	5.30 50.35	0.796	5.57 53.9	0.636	5.73 55.7	0.530	5.84 57.0	.921	.856	.797	12.729

Note.—In the columns marked "Depth and Area," the upper figure is the depth and the lower figure is the area.

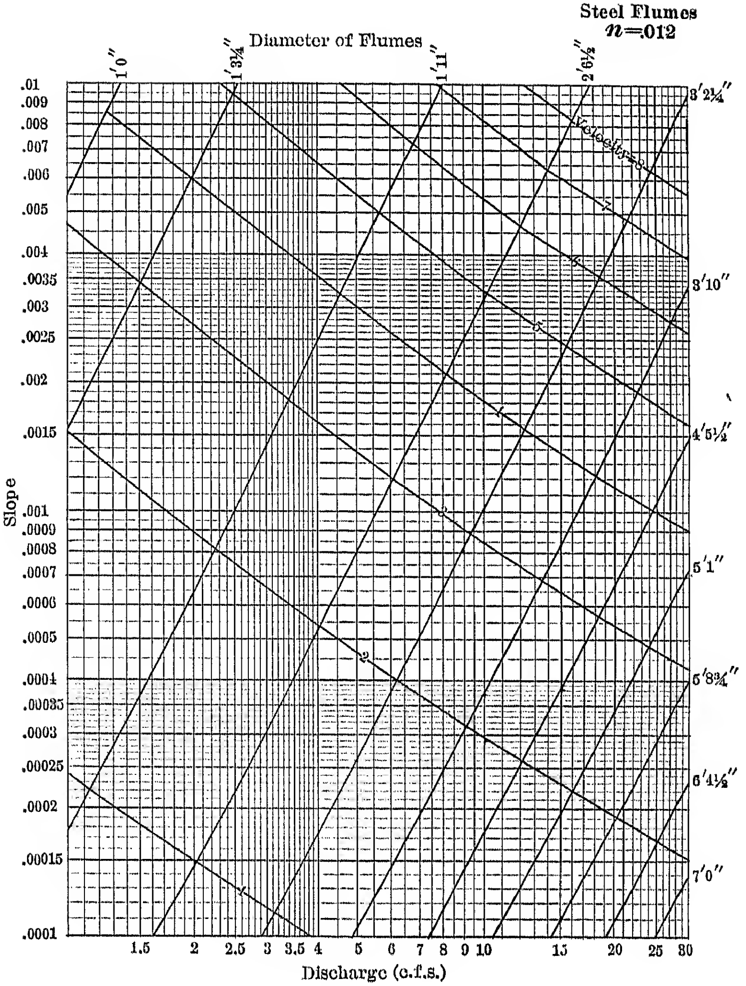


FIG. 29 (Part 1 of 2).—Discharge of Semicircular Steel Flumes.

(Explanation page 81.)

TABLE 24

Semicircular Steel Flumes Flowing Partly Full

(Kutter Formula)

Values by which velocity and discharge of steel flumes given by Fig. 29 should be multiplied to obtain the velocity and discharge of the same flume with the proportionate depth (ratio of depth to diameter) given in the first column.

Proportionate Depth	D = 1 Ft.		D = 2 Ft.		D = 4 Ft.		D = 6 Ft.		D = 10 Ft.	
	Vel'ty	Dis'ge	V	Q	V	Q	V	Q	V	Q
.10	.367	.0485	.384	.0508	.403	.0533	.412	.0545	.420	.0555
.11	.395	.0602	.412	.0628	.431	.0654	.441	.0666	.449	.0678
.12	.424	.0730	.441	.0761	.458	.0790	.468	.0804	.475	.0818
.13	.451	.0872	.468	.0908	.486	.0940	.494	.0953	.499	.0967
.14	.477	.103	.494	.107	.511	.110	.519	.112	.524	.113
.15	.502	.119	.520	.124	.536	.128	.544	.129	.550	.131
.16	.526	.138	.544	.142	.560	.147	.568	.148	.573	.150
.17	.552	.157	.567	.162	.583	.167	.592	.169	.597	.171
.18	.576	.178	.590	.183	.607	.188	.615	.190	.620	.192
.19	.599	.200	.613	.206	.630	.211	.638	.213	.642	.215
.20	.622	.224	.636	.230	.651	.235	.659	.238	.663	.239
.21	.644	.248	.658	.254	.672	.260	.680	.263	.684	.265
.22	.665	.274	.678	.280	.692	.287	.700	.289	.703	.291
.23	.686	.301	.698	.308	.711	.315	.718	.317	.722	.319
.24	.707	.329	.718	.336	.730	.342	.737	.347	.740	.346
.25	.727	.359	.738	.367	.748	.370	.755	.375	.758	.376
.26	.746	.390	.756	.397	.767	.400	.774	.405	.776	.407
.27	.766	.423	.774	.428	.784	.433	.791	.438	.793	.437
.28	.785	.457	.793	.461	.802	.467	.808	.471	.811	.470
.29	.803	.490	.811	.494	.819	.500	.825	.504	.827	.503
.30	.821	.524	.827	.530	.837	.536	.841	.537	.843	.538
.31	.837	.558	.843	.567	.852	.572	.856	.573	.858	.574
.32	.855	.596	.859	.603	.867	.608	.872	.608	.874	.610
.33	.871	.635	.875	.642	.882	.644	.887	.644	.888	.646
.34	.887	.674	.892	.680	.898	.682	.901	.683	.902	.684
.35	.902	.716	.908	.719	.912	.721	.915	.722	.914	.723
.36	.920	.755	.922	.761	.926	.760	.930	.760	.929	.761
.37	.934	.796	.936	.803	.940	.801	.942	.802	.942	.802
.38	.949	.838	.951	.844	.953	.842	.956	.843	.955	.843
.39	.964	.880	.965	.886	.966	.884	.968	.884	.968	.884
.40	.978	.925	.978	.928	.980	.928	.980	.928	.981	.928
.41	.991	.970	.991	.970	.992	.970	.992	.970	.993	.970
.417	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
.42	1.005	1.014	1.003	1.013	1.003	1.013	1.004	1.013	1.004	1.013
.43	1.017	1.058	1.016	1.057	1.015	1.057	1.016	1.057	1.014	1.057
.44	1.030	1.105	1.028	1.105	1.026	1.102	1.027	1.102	1.023	1.102
.45	1.044	1.153	1.040	1.153	1.038	1.149	1.038	1.145	1.034	1.145
.46	1.057	1.200	1.051	1.200	1.049	1.195	1.048	1.192	1.045	1.192
.47	1.068	1.248	1.062	1.247	1.060	1.242	1.058	1.240	1.055	1.239
.48	1.079	1.295	1.073	1.294	1.070	1.287	1.068	1.283	1.064	1.282
.49	1.090	1.342	1.084	1.341	1.079	1.335	1.078	1.330	1.073	1.327
.50	1.101	1.393	1.094	1.389	1.089	1.380	1.087	1.377	1.082	1.373

Note.—For any diameter greater than 10 feet that is likely to be used in practice, the multipliers are practically the same as for the 10 feet diameter.

There is a slight variation with the slope that is not accounted for in the above table. For slopes greater than .0005 the error is usually less than one per cent. For flatter slopes the error is somewhat greater.

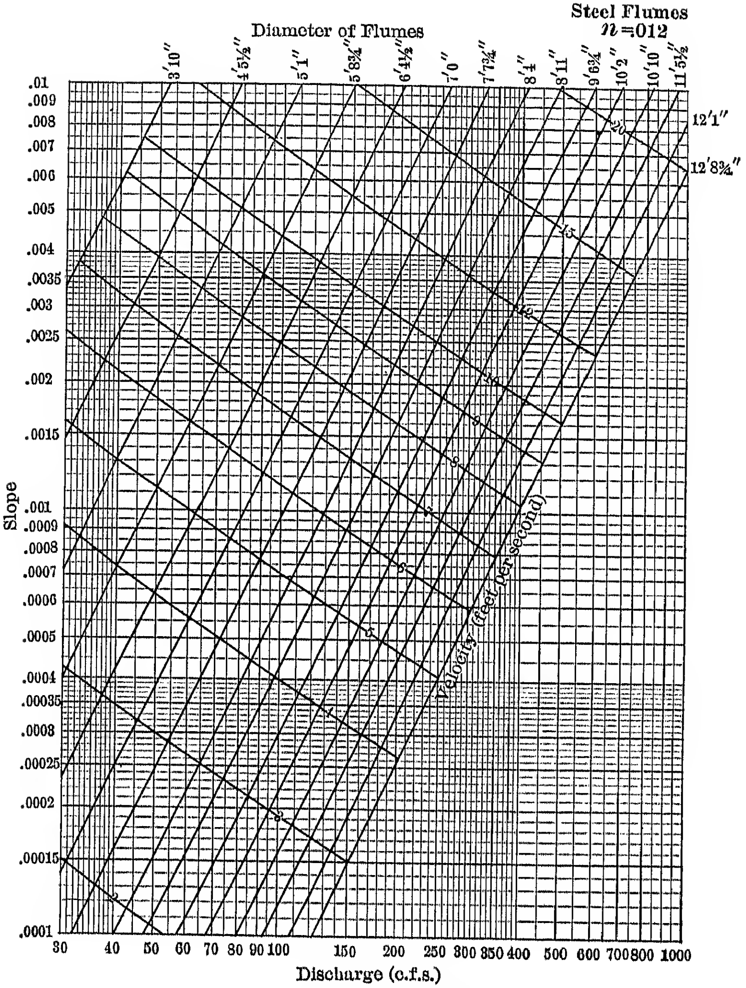


FIG. 29 (Part 2 of 2).—Discharge of Semicircular Steel Flumes.

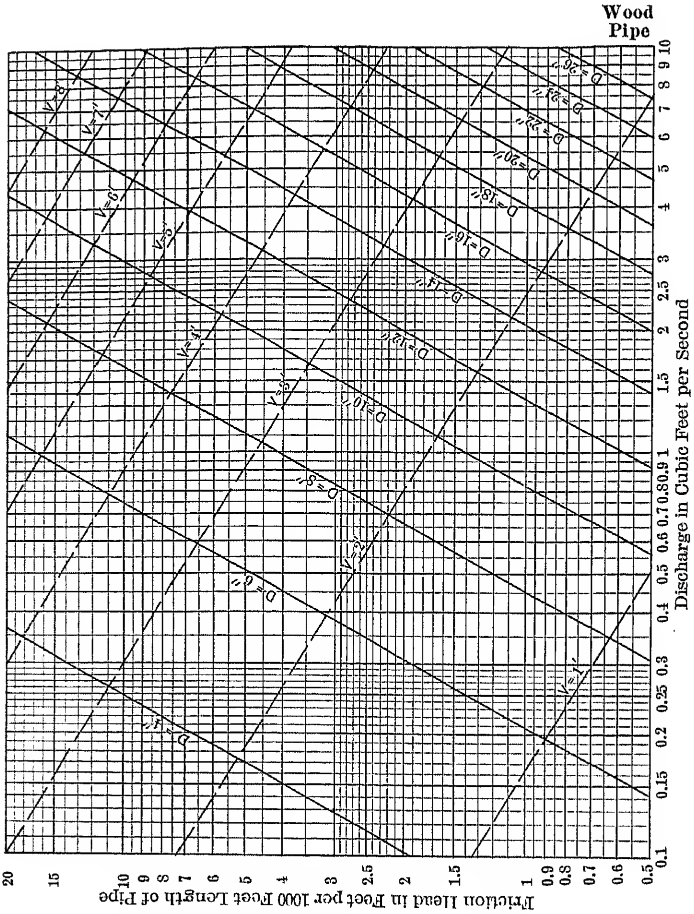


FIG. 30 (Part 1 of 2).—Flow of Water in Wood Stave Pipe.

(See pages 65 to 69.)

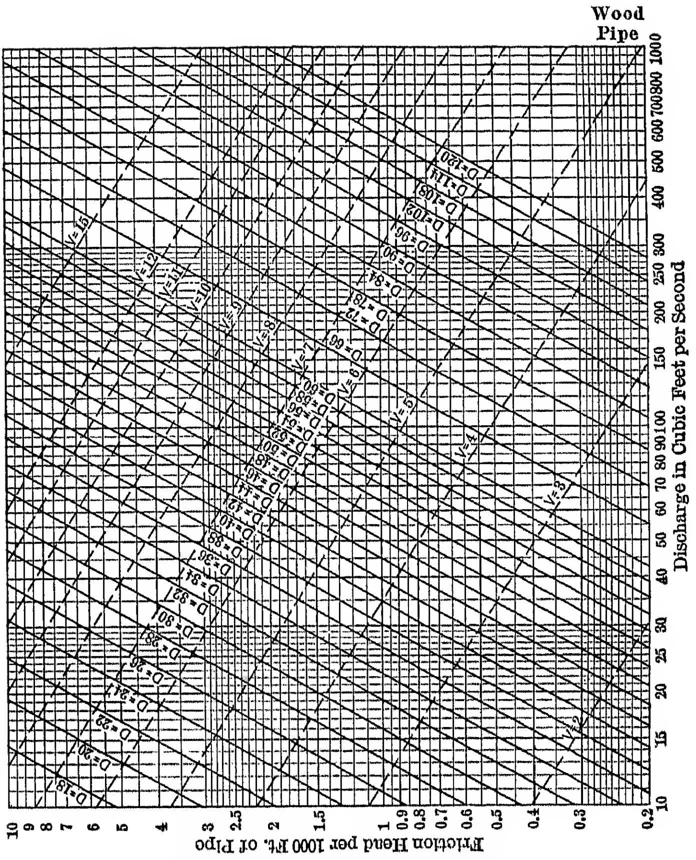


FIG. 30 (Part 2 of 2).—Flow of Water in Wood Stave Pipe.

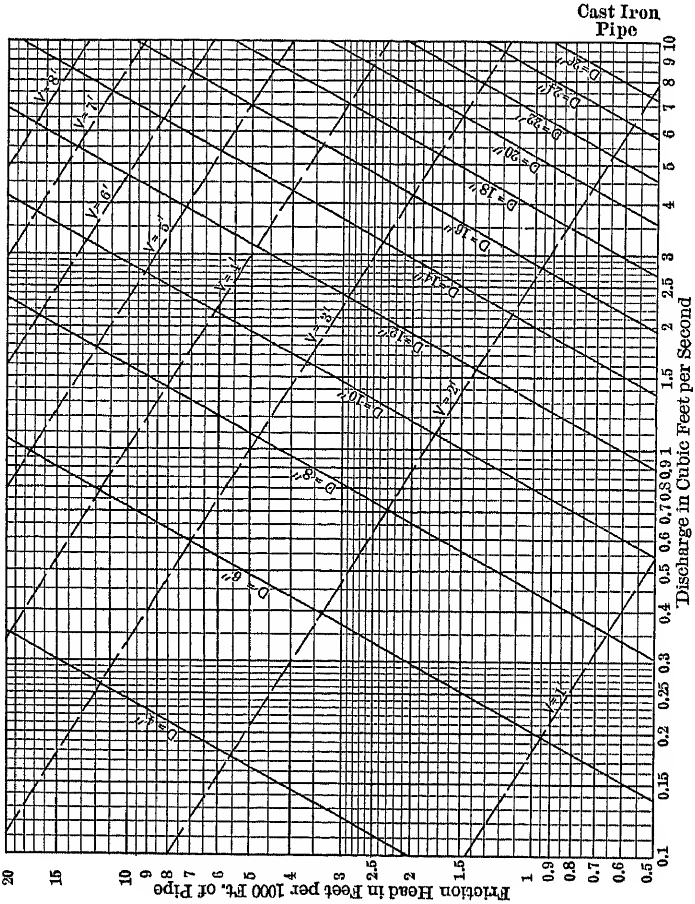


FIG. 31 (Part 1 of 2).—Flow of Water in New Cast-Iron and Smooth Monolithic Concrete Pipe.

(See pages 65 to 69.)

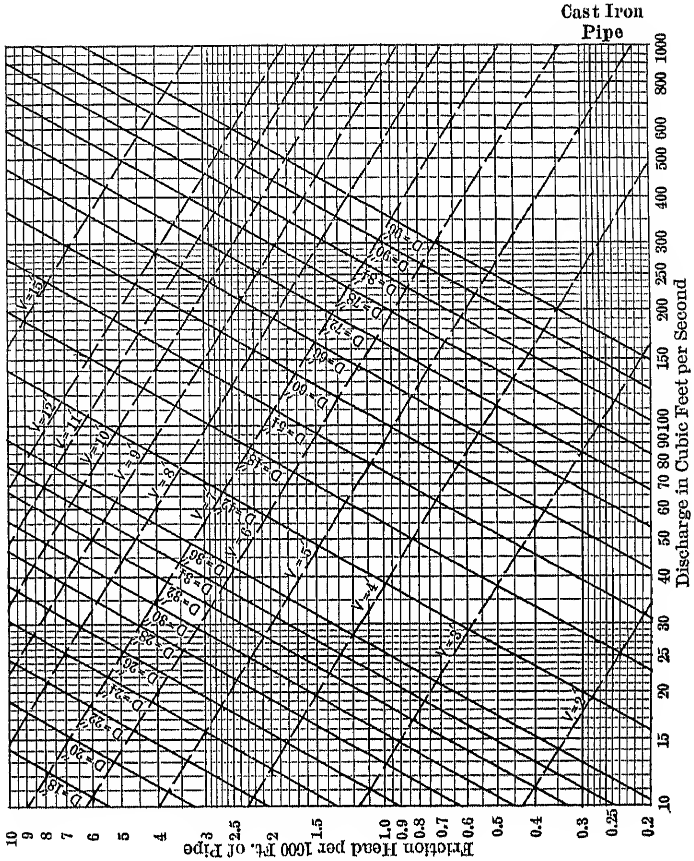


FIG. 31 (Part 2 of 2).—Flow of Water in New Cast-Iron and Smooth Monolithic Concrete Pipe.

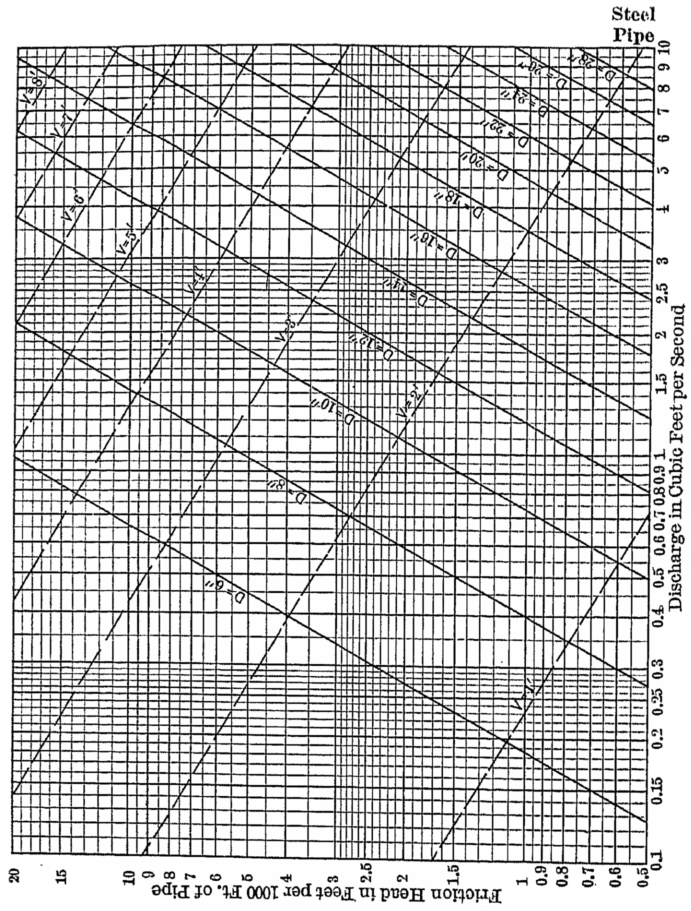


FIG. 32 (Part 1 of 2).—Flow of Water in New Asphalted Riveted Steel and Jointed Concrete Pipe.

(See pages 65 to 69.)

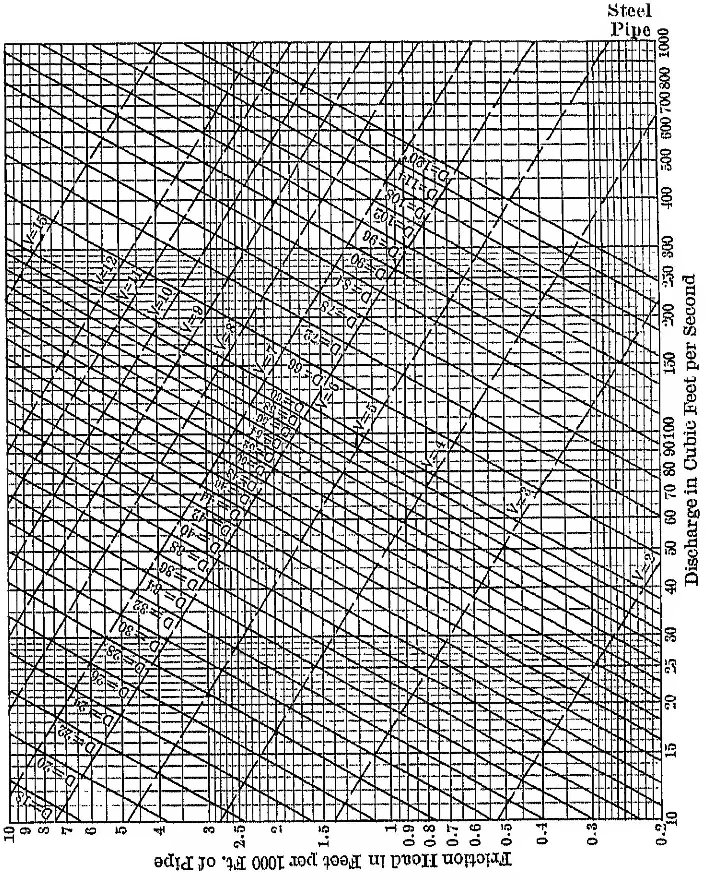


FIG. 32 (Part 2 of 2).—Flow of Water in New Asphalted Riveted Steel and Jointed Concrete Pipe.

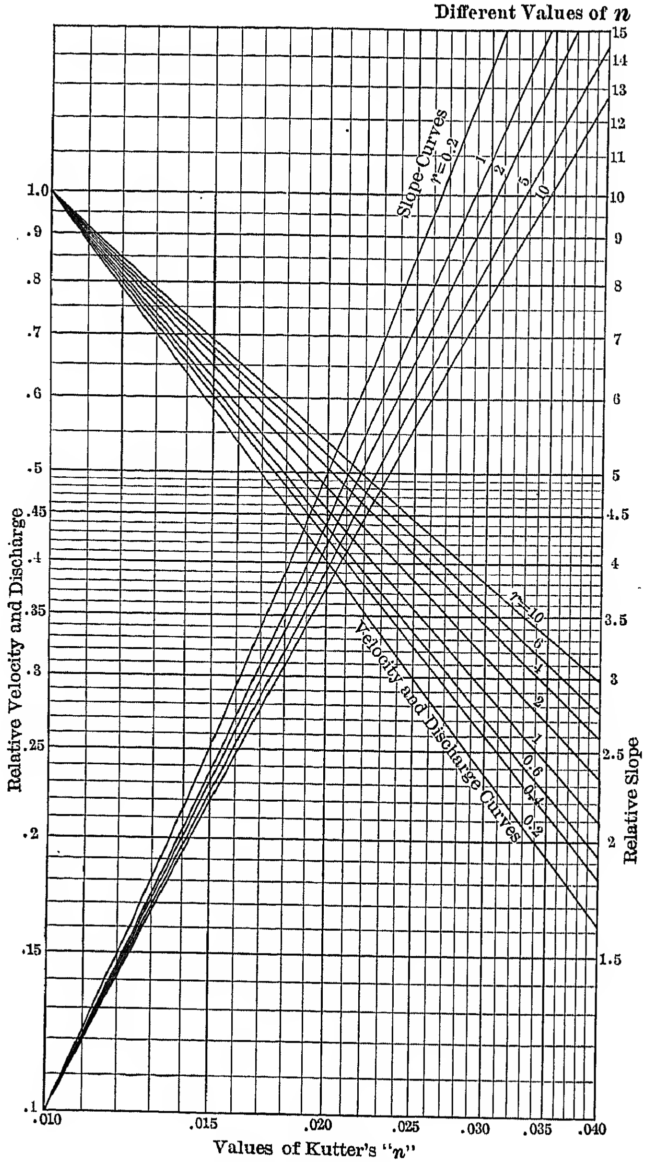


FIG. 33.—Relative Velocities and Slopes for Different Values of "n."

(Explanation page 82.)

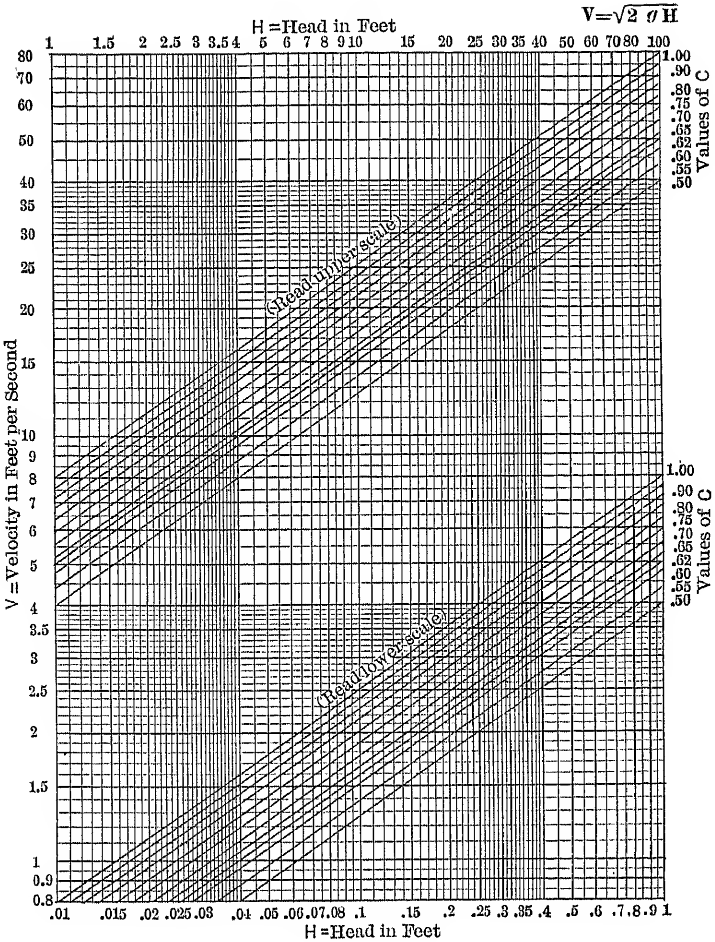


FIG. 34.—Theoretical Velocity Head (Upper line of each group).

This diagram also gives the loss of head through orifices, sluice-gates, pipe intakes, etc., for a given coefficient of discharge: $H' = \frac{1}{C^2}\frac{V^2}{2g}$

Use of Fig. 34

Problem:

What is the theoretical velocity generated by a head of .05 foot?

Solution:

At the intersection of the upper line of the lower group

with the vertical line representing $H = .05$ on the lower scale, read $V = 1.8$ feet per second.

Problem:

What is the theoretical head required to generate a velocity of 40 feet per second?

Solution:

At the intersection of the upper line of the upper group with the horizontal line representing $V = 40$, read on the upper scale $H = 25$ feet.

Problem:

What total head is required to force water through an opening, whose coefficient of discharge is 0.75, with a velocity of 5 feet per second?

Solution:

At the intersection of the horizontal line for $V = 5$ with the inclined line marked .75 (found in the lower group), read on the lower scale $H = 0.7$ foot.

NOTE.—The velocity used in this problem is that obtained by dividing the discharge by the full area of the opening, and is not the actual velocity at the contracted section, which, in this case, would be more nearly $0.98\ \sqrt{2g \times 0.7} = 6.7$.

Use of Fig. 35

Problem:

What is the discharge of a sluice opening 4 feet square having contraction suppressed on bottom and two sides when the difference in elevation of water surface above and below the opening is 0.5 foot?

Solution:

The area of this opening is 16 square feet. At the intersection of the horizontal line for $H = 0.5$ with the imaginary line for area = 16 we read on the lower scale $Q = 55$ c. f. s. for a standard sharp-edged orifice; multiplying this by 1.29 we get 71 c. f. s. as the discharge for the sluice opening in question.

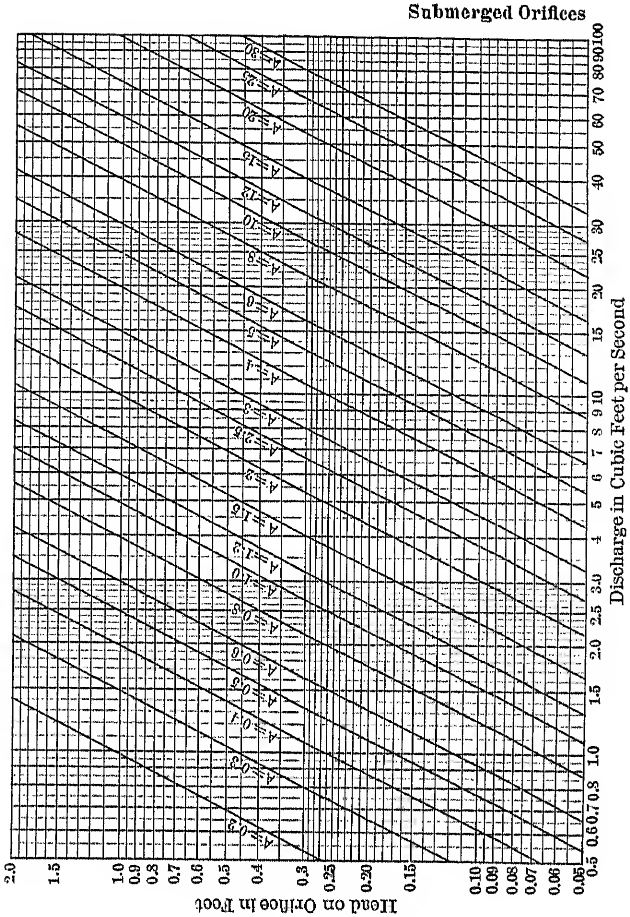


FIG. 35.—Discharge of Sharp-edged Submerged Orifices. $Q = 0.61\ A\ \sqrt{2\ gH}$

Approximate multipliers of discharge for Sluice Gates:

With bottom contraction suppressed = 1.07 (coeff. of discharge = 0.65)
With bottom and one side suppressed = 1.14 (coeff. of discharge = 0.70)
With bottom and two sides suppressed = 1.29 (coeff. of discharge = 0.79)
With all sides suppressed = 1.56 (coeff. of discharge = 0.95)

TABLE 25

Coefficients C' to be Applied to a Discharge Given by Figs. 36 and 37 for a Head H to Give Discharge of Same Weir Submerged, Computed from the Formula $C' = \frac{Q_1}{Q} = \frac{(n\,H)^{\frac{3}{2}}}{H^{\frac{3}{2}}}$. n is Herschel's Coefficient for Submerged Weirs

$d \div H$ / Hundredths / Tenths	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	1.000	1.006	1.009	1.009	1.011	1.011	1.011	1.009	1.009	1.007
.1	1.007	1.005	1.003	1.000	.997	.994	.991	.988	.983	.981
.2	.978	.973	.970	.966	.963	.958	.955	.951	.946	.942
.3	.939	.935	.931	.926	.921	.917	.913	.909	.903	.900
.4	.895	.891	.885	.881	.875	.871	.865	.859	.854	.848
.5	.842	.837	.831	.825	.819	.812	.806	.799	.792	.785
.6	.778	.771	.764	.756	.748	.740	.733	.724	.715	.707
.7	.698	.689	.680	.670	.660	.649	.639	.626	.615	.603
.8	.589	.576	.562	.547	.531	.517	.501	.486	.469	.453
.9	.435	.416	.396	.375	.351	.323	.293	.255	.209	.144

To use this table, read the discharge from Fig. 36 or 37 for free fall and multiply by the appropriate coefficient taken from the table to obtain the discharge of same weir with crest submerged to a depth d, below downstream water surface.

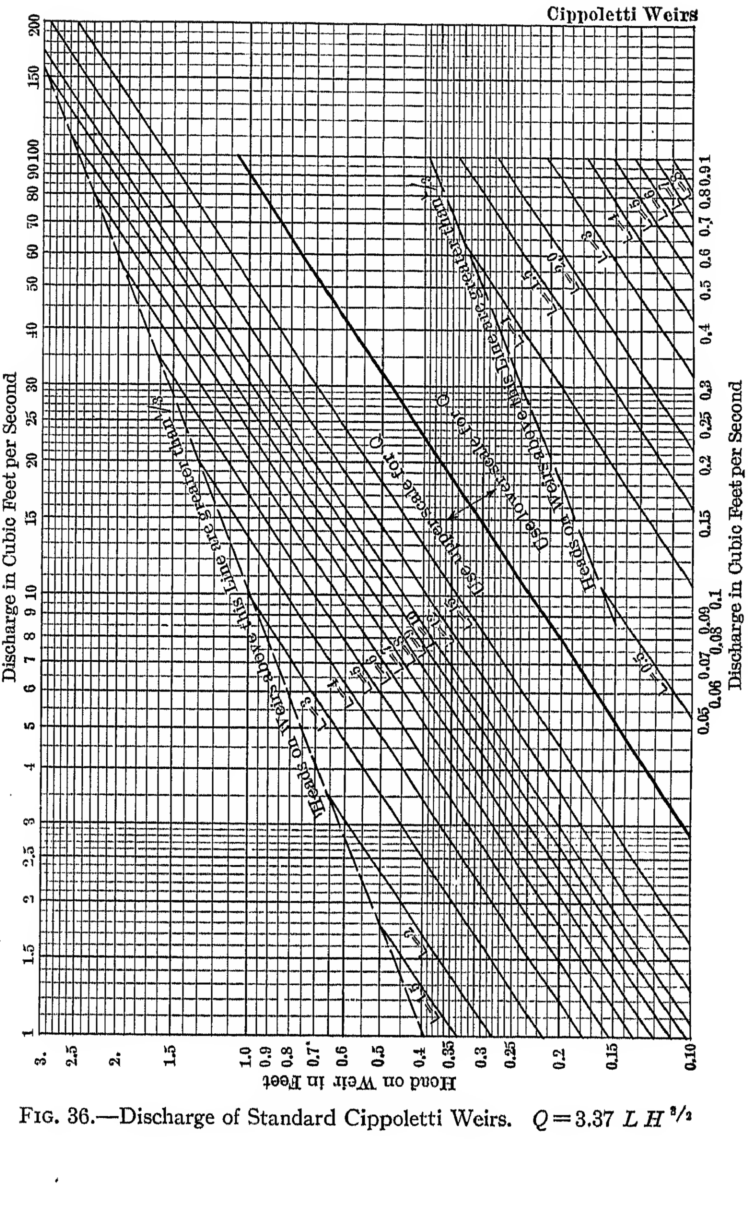


FIG. 36.—Discharge of Standard Cippoletti Weirs. $Q = 3.37\, L\, H^{3/2}$

TABLE 26

COEFFICIENTS C TO BE APPLIED TO A DISCHARGE TAKEN FROM FIGS. 36 AND 37 FOR A HEAD H, TO OBTAIN THE DISCHARGE OF THE SAME WEIR WHEN A VELOCITY OF APPROACH v EXISTS

(h = velocity of head).

v	h	$h^{\frac{3}{2}}$	H											
			0.2	0.4	0.6	0.8	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
0.4....	0.0025	0.0002	1.014	1.007	1.004	1.004	1.004	1.002	1.002	1.002	1.001	1.001	1.001	1.001
0.5....	.0039	.0003	1.027	1.013	1.009	1.006	1.006	1.004	1.003	1.002	1.002	1.002	1.001	1.001
0.6....	.0056	.0005	1.037	1.019	1.013	1.009	1.008	1.005	1.004	1.003	1.003	1.002	1.002	1.002
0.7....	.0076	.0007	1.050	1.026	1.017	1.013	1.011	1.007	1.006	1.004	1.004	1.003	1.003	1.002
0.8....	.0099	.0010	1.064	1.033	1.022	1.016	1.014	1.009	1.007	1.006	1.005	1.004	1.003	1.003
0.9....	.0126	.0014	1.082	1.042	1.029	1.021	1.018	1.012	1.009	1.007	1.006	1.005	1.005	1.004
1.0....	.0155	.0019	1.098	1.051	1.034	1.027	1.022	1.015	1.011	1.009	1.007	1.006	1.005	1.005
1.1....	.0188	.0025	1.122	1.062	1.041	1.031	1.026	1.017	1.013	1.011	1.009	1.008	1.007	1.006
1.2....	.0224	.0033	1.141	1.072	1.049	1.037	1.031	1.021	1.016	1.013	1.011	1.009	1.008	1.007
1.3....	.0263	.0041	1.163	1.084	1.057	1.043	1.036	1.024	1.018	1.015	1.012	1.011	1.009	1.008
1.4....	.0305	.0051	1.186	1.096	1.066	1.050	1.041	1.028	1.021	1.017	1.014	1.012	1.011	1.010
1.5....	.0350	.0064	1.208	1.109	1.075	1.057	1.047	1.032	1.024	1.019	1.016	1.014	1.012	1.011
1.6....	.0398	.0079	1.225	1.122	1.084	1.065	1.052	1.035	1.027	1.022	1.018	1.016	1.014	1.012
1.7....	.0449	.0095	1.254	1.135	1.093	1.071	1.059	1.040	1.031	1.025	1.021	1.018	1.016	1.014
1.8....	.0504	.0111	1.277	1.149	1.104	1.080	1.065	1.045	1.034	1.027	1.023	1.020	1.017	1.016
1.9....	.0561	.0132	1.308	1.165	1.115	1.089	1.072	1.049	1.038	1.030	1.026	1.022	1.019	1.017
2.0....	.0622	.0154	1.335	1.181	1.126	1.097	1.079	1.055	1.042	1.034	1.028	1.025	1.021	1.019
2.1....	.0686	.0179	1.363	1.197	1.137	1.106	1.087	1.060	1.046	1.037	1.031	1.027	1.024	1.021
2.2....	.0752	.0206	1.391	1.213	1.149	1.118	1.094	1.065	1.050	1.039	1.034	1.029	1.026	1.023
2.3....	.0822	.0235	1.420	1.231	1.161	1.124	1.102	1.071	1.054	1.044	1.037	1.032	1.028	1.025
2.4....	.0895	.0268	1.449	1.248	1.176	1.134	1.110	1.077	1.059	1.047	1.040	1.034	1.030	1.027
2.5....	.0972	.0303	1.480	1.266	1.187	1.145	1.119	1.083	1.063	1.051	1.048	1.037	1.033	1.029
2.6....	.1051	.0340	1.511	1.285	1.200	1.155	1.128	1.088	1.068	1.055	1.046	1.040	1.035	1.032
2.7....	.1133	.0381	1.542	1.303	1.213	1.166	1.137	1.095	1.073	1.059	1.050	1.043	1.038	1.034
2.8....	.1219	.0426	1.573	1.322	1.228	1.178	1.146	1.100	1.078	1.063	1.053	1.046	1.041	1.036
2.9....	.1307	.0472	1.606	1.341	1.242	1.189	1.155	1.108	1.083	1.067	1.057	1.049	1.043	1.039
3.0....	0.1399	0.0524	1.637	1.361	1.256	1.199	1.165	1.115	1.088	1.072	1.061	1.053	1.046	1.041

To use this table, read the discharge from Figs. 36 or 37 for the measured head and multiply by the appropriate coefficient taken from the above table to obtain the discharge when a velocity of approach v exists.

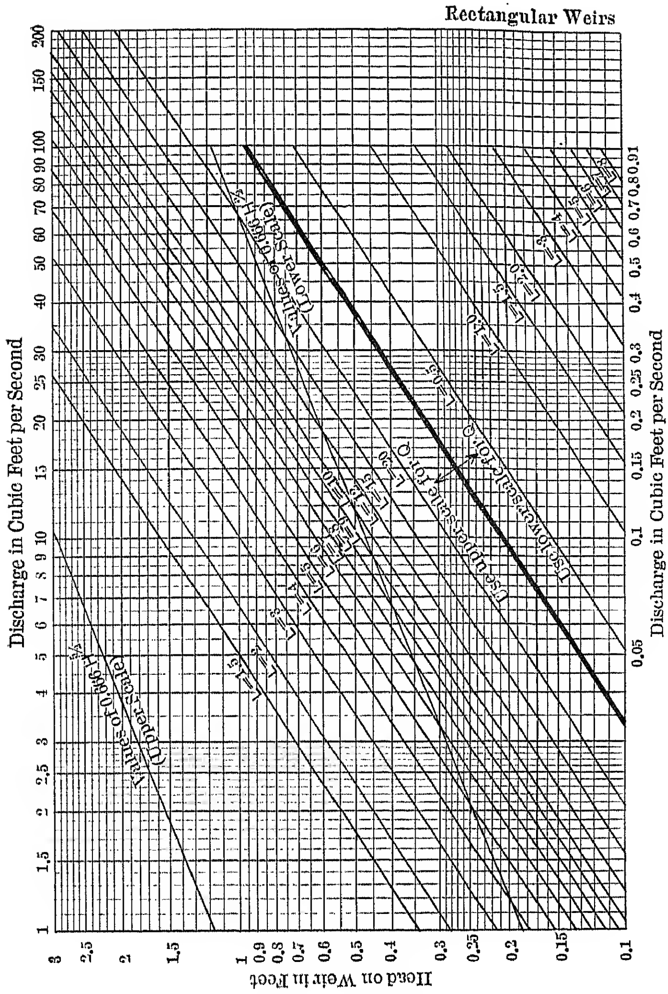


FIG. 37.—Discharge of Standard Suppressed Rectangular Weirs — $Q = 3.33 LH^{3/2}$ and Discharge of Standard Contracted Rectangular Weirs — $Q = 3.33\ LH^{3/2} - .666\ H^{5/2}$

NOTE.—For Contracted Weirs this diagram is not accurate for heads greater than one-third the crest-length.

TABLE 27

DISCHARGE OVER SHARP-CRESTED VERTICAL WEIRS WITHOUT END CONTRACTIONS, IN CUBIC FEET PER SECOND PER FOOT OF LENGTH OF WEIR FOR SMALL HEADS

Head, in Feet	Weir 0.5 Ft. High	Weir 0.75 Ft. High	Weir 1.00 Ft. High	Weir 1.50 Ft. High	Weir 2.00 Ft. High	Weir 3.00 Ft. High	Weir 4.00 Ft. High	Weir 6.00 Ft. High
0.200	0.315	0.314	0.313	0.312	0.311	0.310	0.309	.....
0.205	0.327	0.326	0.325	0.324	0.323	0.322	0.321	.....
0.210	0.340	0.337	0.336	0.335	0.334	0.333	0.332	.....
0.215	0.352	0.351	0.350	0.348	0.347	0.346	0.346	.....
0.220	0.365	0.363	0.360	0.359	0.357	0.356	0.355	.....
0.225	0.377	0.375	0.372	0.370	0.369	0.368	0.367	.....
0.230	0.392	0.388	0.385	0.383	0.382	0.381	0.380	.....
0.235	0.404	0.400	0.398	0.396	0.394	0.393	0.392	.....
0.240	0.420	0.415	0.412	0.408	0.406	0.405	0.404	.....
0.245	0.433	0.427	0.425	0.422	0.420	0.417	0.416	.....
0.250	0.446	0.442	0.438	0.435	0.434	0.432	0.430	.....
0.255	0.460	0.453	0.450	0.447	0.445	0.443	0.442	.....
0.260	0.475	0.468	0.465	0.460	0.458	0.456	0.455	.....
0.265	0.490	0.483	0.478	0.475	0.473	0.470	0.468	.....
0.270	0.503	0.497	0.493	0.488	0.486	0.484	0.483	.....
0.275	0.515	0.508	0.505	0.501	0.498	0.496	0.495	.....
0.280	0.530	0.524	0.518	0.514	0.510	0.507	0.506	.....
0.285	0.546	0.537	0.532	0.526	0.523	0.520	0.517	.....
0.290	0.560	0.552	0.547	0.544	0.540	0.535	0.533	.....
0.295	0.576	0.566	0.560	0.555	0.552	0.548	0.546	.....
0.300	0.595	0.584	0.576	0.570	0.566	0.563	0.560	.....
0.305	0.610	0.595	0.588	0.582	0.577	0.575	0.572	.....
0.310	0.625	0.612	0.605	0.598	0.595	0.590	0.586	.....
0.315	0.640	0.627	0.620	0.613	0.608	0.605	0.602	.....
0.320	0.655	0.645	0.636	0.630	0.625	0.620	0.617	.....
0.325	0.670	0.655	0.650	0.641	0.636	0.632	0.630	.....
0.330	0.690	0.672	0.665	0.656	0.652	0.647	0.645	.....
0.335	0.705	0.690	0.680	0.670	0.665	0.660	0.657	.....
0.340	0.720	0.705	0.697	0.688	0.683	0.675	0.673	.....
0.345	0.738	0.720	0.710	0.703	0.696	0.692	0.687	.....
0.350	0.755	0.735	0.726	0.717	0.712	0.705	0.702	.....
0.355	0.770	0.752	0.743	0.732	0.725	0.720	0.717	.....
0.360	0.790	0.772	0.760	0.750	0.745	0.737	0.733	.....
0.365	0.805	0.786	0.775	0.764	0.757	0.750	0.746	.....
0.370	0.824	0.802	0.792	0.780	0.775	0.766	0.762	.....
0.375	0.840	0.817	0.805	0.795	0.790	0.782	0.777	.....
0.380	0.860	0.836	0.825	0.813	0.805	0.798	0.795	.....
0.385	0.875	0.853	0.840	0.826	0.820	0.810	0.806	.....
0.390	0.896	0.870	0.857	0.845	0.837	0.830	0.825	.....
0.395	0.910	0.885	0.870	0.860	0.852	0.845	0.838	.....
0.400	0.930	0.905	0.893	0.875	0.870	0.860	0.855	0.850
0.405	0.950	0.922	0.910	0.895	0.885	0.875	0.870	0.860
0.410	0.970	0.940	0.925	0.910	0.903	0.895	0.885	0.876
0.415	0.990	0.956	0.943	0.925	0.917	0.908	0.903	0.895
0.420	1.005	0.975	0.958	0.943	0.935	0.924	0.917	0.910

NOTE.—This table covers the same ground as the first fifteen lines of Table 28 but in greater detail. This table should not be used where the weir is submerged, nor unless the overfalling sheet is aerated on the downstream face of the weir. This table is reproduced by permission of the author, Prof. R. R. Lyman of the University of Utah. It was originally published in Trans. Am. Soc. C. E., 1914, and in a Bulletin of the U. of U.

TABLE 27 (*Continued*)

DISCHARGE IN CUBIC FEET PER SECOND PER FOOT OF LENGTH OF WEIR

Head, in Feet	Weir 0.5 Ft. High	Weir 0.75 Ft. High	Weir 1.00 Ft. High	Weir 1.50 Ft. High	Weir 2.00 Ft. High	Weir 3.00 Ft. High	Weir 4.00 Ft. High	Weir 6.00 Ft. High
0.425	1.020	0.995	0.977	0.963	0.952	0.942	0.935	0.926
0.430	1.045	1.010	0.996	0.980	0.970	0.957	0.952	0.945
0.435	1.065	1.030	1.010	0.996	0.986	0.975	0.970	0.960
0.440	1.083	1.045	1.026	1.010	1.000	0.992	0.985	0.976
0.445	1.100	1.063	1.045	1.026	1.015	1.005	1.000	0.994
0.450	1.120	1.080	1.060	1.040	1.030	1.015	1.010	1.030
0.455	1.140	1.100	1.080	1.057	1.047	1.035	1.023	1.016
0.460	1.164	1.125	1.105	1.085	1.074	1.056	1.050	1.043
0.465	1.185	1.140	1.120	1.100	1.090	1.075	1.067	1.057
0.470	1.205	1.163	1.143	1.120	1.106	1.095	1.085	1.077
0.475	1.230	1.185	1.162	1.140	1.125	1.110	1.105	1.096
0.480	1.250	1.205	1.185	1.160	1.150	1.133	1.125	1.115
0.485	1.270	1.223	1.200	1.175	1.163	1.150	1.140	1.130
0.490	1.290	1.245	1.220	1.200	1.183	1.166	1.160	1.150
0.495	1.310	1.265	1.233	1.215	1.200	1.186	1.176	1.166
0.500	1.335	1.285	1.263	1.235	1.220	1.203	1.195	1.185
0.505	1.355	1.300	1.280	1.250	1.236	1.220	1.210	1.202
0.510	1.370	1.320	1.296	1.270	1.257	1.237	1.225	1.220
0.515	1.390	1.340	1.317	1.287	1.274	1.255	1.244	1.235
0.520	1.415	1.360	1.335	1.305	1.290	1.273	1.260	1.252
0.525	1.440	1.380	1.355	1.325	1.310	1.290	1.280	1.274
0.530	1.465	1.405	1.375	1.346	1.330	1.310	1.300	1.293
0.535	1.490	1.425	1.400	1.365	1.353	1.335	1.320	1.310
0.540	1.510	1.440	1.415	1.385	1.365	1.350	1.336	1.327
0.545	1.530	1.465	1.435	1.403	1.385	1.365	1.355	1.345
0.550	1.555	1.490	1.460	1.425	1.405	1.385	1.370	1.365
0.555	1.575	1.505	1.475	1.440	1.420	1.400	1.390	1.380
0.560	1.595	1.525	1.495	1.460	1.435	1.415	1.405	1.395
0.565	1.616	1.545	1.515	1.475	1.455	1.435	1.420	1.410
0.570	1.640	1.570	1.535	1.500	1.475	1.455	1.440	1.430
0.575	1.665	1.590	1.555	1.517	1.500	1.475	1.460	1.450
0.580	1.686	1.610	1.576	1.537	1.517	1.495	1.480	1.470
0.585	1.713	1.635	1.605	1.565	1.540	1.520	1.505	1.495
0.590	1.740	1.670	1.630	1.590	1.570	1.545	1.530	1.523
0.595	1.760	1.685	1.650	1.605	1.585	1.560	1.543	1.535
0.600	1.790	1.700	1.675	1.625	1.605	1.580	1.565	1.555
0.605	1.805	1.730	1.695	1.655	1.627	1.605	1.590	1.580
0.610	1.830	1.750	1.715	1.675	1.650	1.625	1.610	1.600
0.615	1.855	1.775	1.735	1.695	1.675	1.650	1.630	1.620
0.620	1.880	1.795	1.760	1.710	1.690	1.670	1.650	1.640
0.625	1.905	1.815	1.780	1.730	1.705	1.685	1.670	1.665
0.630	1.930	1.845	1.805	1.760	1.730	1.705	1.694	1.687
0.635	1.955	1.875	1.835	1.785	1.760	1.725	1.710	1.700
0.640	1.980	1.900	1.860	1.815	1.790	1.760	1.740	1.730
0.645	2.010	1.915	1.870	1.820	1.800	1.770	1.750	1.740
0.650	2.035	1.930	1.890	1.840	1.810	1.780	1.760	1.750
0.655	2.060	1.960	1.915	1.860	1.830	1.805	1.785	1.775
0.660	2.085	1.985	1.945	1.890	1.865	1.830	1.815	1.805
0.665	2.110	2.005	1.965	1.910	1.880	1.850	1.830	1.820
0.670	2.135	2.025	1.980	1.930	1.900	1.870	1.850	1.840

TABLE 27 (*Continued*)

DISCHARGE IN CUBIC FEET PER SECOND PER FOOT OF LENGTH OF WEIR

Head, in Feet	Weir 0.5 Ft. High	Weir 0.75 Ft. High	Weir 1.00 Ft. High	Weir 1.50 Ft. High	Weir 2.00 Ft. High	Weir 3.00 Ft. High	Weir 4.00 Ft. High	Weir 6.00 Ft. High
0.675	2.160	2.055	2.000	1.945	1.910	1.880	1.860	1.850
0.680	2.185	2.075	2.030	1.980	1.945	1.910	1.895	1.885
0.685	2.210	2.095	2.050	1.990	1.960	1.925	1.905	1.895
0.690	2.240	2.125	2.075	2.025	1.990	1.960	1.935	1.925
0.695	2.260	2.150	2.095	2.040	2.005	1.970	1.945	1.930
0.700	2.295	2.180	2.130	2.070	2.030	1.995	1.975	1.965
0.705	2.325	2.200	2.155	2.100	2.065	2.025	2.000	1.985
0.710	2.350	2.220	2.170	2.115	2.085	2.040	2.020	2.005
0.715	2.380	2.250	2.195	2.140	2.105	2.060	2.035	2.025
0.720	2.410	2.275	2.220	2.160	2.125	2.085	2.060	2.045
0.725	2.435	2.300	2.245	2.180	2.155	2.115	2.090	2.080
0.730	2.465	2.325	2.270	2.200	2.175	2.135	2.110	2.095
0.735	2.490	2.350	2.295	2.230	2.190	2.150	2.130	2.120
0.740	2.520	2.375	2.320	2.250	2.210	2.170	2.140	2.130
0.745	2.550	2.405	2.340	2.275	2.235	2.200	2.170	2.160
0.750	2.585	2.430	2.375	2.300	2.260	2.225	2.190	2.180
0.755	2.605	2.455	2.400	2.325	2.285	2.245	2.220	2.200
0.760	2.640	2.480	2.415	2.340	2.300	2.270	2.240	2.230
0.765	2.670	2.510	2.440	2.370	2.330	2.290	2.265	2.255
0.770	2.700	2.540	2.470	2.400	2.350	2.300	2.285	2.275
0.775	2.730	2.560	2.500	2.420	2.375	2.330	2.310	2.300
0.780	2.760	2.590	2.515	2.440	2.400	2.345	2.330	2.325
0.785	2.790	2.610	2.550	2.460	2.415	2.365	2.345	2.335
0.790	2.820	2.630	2.570	2.480	2.430	2.380	2.360	2.350
0.795	2.850	2.660	2.595	2.510	2.460	2.410	2.380	2.365
0.800	2.890	2.700	2.625	2.550	2.500	2.440	2.410	2.400
0.805	2.910	2.730	2.660	2.575	2.520	2.465	2.425	2.410
0.810	2.940	2.755	2.680	2.595	2.545	2.485	2.445	2.425
0.815	2.975	2.780	2.700	2.610	2.565	2.505	2.460	2.440
0.820	3.010	2.810	2.735	2.640	2.590	2.530	2.500	2.480
0.825	3.045	2.840	2.770	2.670	2.610	2.560	2.530	2.510
0.830	3.070	2.870	2.790	2.700	2.640	2.580	2.550	2.535
0.835	3.100	2.905	2.830	2.730	2.675	2.610	2.580	2.565
0.840	3.130	2.930	2.840	2.760	2.695	2.630	2.600	2.590
0.845	3.160	2.950	2.880	2.785	2.730	2.650	2.615	2.605
0.850	3.190	2.990	2.910	2.800	2.750	2.680	2.650	2.630
0.855	3.230	3.015	2.930	2.840	2.780	2.710	2.670	2.650
0.860	3.260	3.040	2.960	2.860	2.800	2.735	2.700	2.680
0.865	3.290	3.070	2.980	2.880	2.815	2.750	2.715	2.695
0.870	3.320	3.100	3.010	2.910	2.840	2.780	2.740	2.720
0.875	3.350	3.120	3.035	2.930	2.870	2.795	2.765	2.750
0.880	3.395	3.160	3.070	2.965	2.900	2.820	2.790	2.780
0.885	3.415	3.180	3.090	2.980	2.920	2.840	2.810	2.790
0.890	3.445	3.200	3.120	3.010	2.940	2.860	2.825	2.820
0.895	3.480	3.235	3.150	3.040	2.970	2.895	2.860	2.845
0.900	3.520	3.270	3.180	3.070	3.000	2.920	2.890	2.870
0.905	3.550	3.300	3.210	3.100	3.035	2.940	2.910	2.890
0.910	3.580	3.330	3.235	3.120	3.055	2.970	2.930	2.910
0.915	3.620	3.360	3.260	3.155	3.085	3.000	2.955	2.935

TABLE 27 (*Continued*)

DISCHARGE IN CUBIC FEET PER SECOND PER FOOT OF LENGTH OF WEIR

Head, in Feet	Weir 0.5 Ft. High	Weir 0.75 Ft. High	Weir 1.00 Ft. High	Weir 1.50 Ft. High	Weir 2.00 Ft. High	Weir 3.00 Ft. High	Weir 4.00 Ft. High	Weir 6.00 Ft. High
0.920	3.655	3.390	3.290	3.180	3.110	3.030	2.980	2.960
0.925	3.690	3.420	3.325	3.210	3.140	3.055	3.010	2.990
0.930	3.720	3.445	3.350	3.230	3.160	3.075	3.030	3.010
0.935	3.760	3.480	3.380	3.250	3.180	3.100	3.060	3.040
0.940	3.800	3.510	3.405	3.290	3.210	3.130	3.080	3.060
0.945	3.830	3.540	3.430	3.315	3.240	3.150	3.110	3.090
0.950	3.870	3.580	3.470	3.350	3.260	3.180	3.140	3.120
0.955	3.900	3.610	3.500	3.380	3.295	3.200	3.165	3.140
0.960	3.940	3.640	3.540	3.400	3.325	3.235	3.190	3.170
0.965	3.980	3.680	3.570	3.430	3.355	3.260	3.210	3.190
0.970	4.010	3.700	3.590	3.450	3.370	3.275	3.235	3.200
0.975	4.040	3.740	3.625	3.490	3.405	3.310	3.270	3.250
0.980	4.080	3.770	3.650	3.520	3.430	3.330	3.290	3.270
0.985	4.120	3.800	3.690	3.555	3.460	3.365	3.320	3.300
0.990	4.150	3.830	3.710	3.580	3.480	3.380	3.340	3.320
0.995	4.180	3.850	3.730	3.590	3.510	3.400	3.360	3.330
1.000	4.230	3.900	3.780	3.640	3.555	3.440	3.400	3.375
1.010	4.300	3.970	3.840	3.710	3.600	3.500	3.450	3.420
1.020	4.380	4.030	3.900	3.760	3.670	3.560	3.500	3.480
1.030	4.450	4.100	3.970	3.820	3.720	3.600	3.560	3.540
1.040	4.520	4.170	4.040	3.880	3.780	3.670	3.620	3.590
1.050	4.610	4.240	4.120	3.950	3.850	3.730	3.670	3.650
1.060	4.800	4.320	4.180	4.020	3.910	3.790	3.740	3.710
1.070	4.760	4.370	4.220	4.070	3.960	3.830	3.770	3.750
1.080	4.820	4.430	4.280	4.130	4.010	3.890	3.820	3.800
1.090	4.900	4.480	4.340	4.180	4.060	3.930	3.870	3.840
1.100	4.980	4.570	4.420	4.240	4.140	3.990	3.940	3.910
1.110	5.060	4.640	4.480	4.320	4.190	4.060	4.000	3.960
1.120	5.150	4.710	4.560	4.370	4.240	4.120	4.050	4.010
1.130	5.220	4.780	4.610	4.420	4.300	4.170	4.100	4.070
1.140	5.300	4.840	4.670	4.480	4.360	4.210	4.160	4.130
1.150	5.380	4.910	4.740	4.560	4.420	4.270	4.210	4.180
1.160	5.450	4.980	4.800	4.610	4.480	4.330	4.260	4.220
1.170	5.510	5.050	4.870	4.670	4.540	4.380	4.320	4.280
1.180	5.600	5.130	4.950	4.740	4.610	4.440	4.380	4.340
1.190	5.680	5.200	5.000	4.800	4.660	4.500	4.420	4.400
1.200	5.780	5.250	5.075	4.870	4.720	4.560	4.480	4.440
1.210	5.860	5.340	4.150	4.940	4.780	4.610	4.540	4.500
1.220	5.940	5.420	5.250	5.000	4.860	4.680	4.610	4.590
1.230	6.000	5.460	5.270	5.050	4.910	4.720	4.640	4.610
1.240	6.100	5.550	5.360	5.150	4.980	4.800	4.720	4.680
1.250	6.200	5.620	5.430	5.220	5.050	4.860	4.780	4.740
1.260	6.275	5.675	5.500	5.275	5.100	4.910	4.830	4.800
1.270	.....	5.750	5.560	5.325	5.180	4.970	4.890	4.850
1.280	.....	5.820	5.620	5.380	5.225	5.000	4.940	4.900
1.290	.....	5.900	5.680	5.450	5.275	5.075	5.000	4.960
1.300	.....	5.975	5.775	5.525	5.350	5.150	5.050	5.020
1.310	.....	6.060	5.850	5.600	5.425	5.225	5.130	5.080
1.320	.....	6.150	5.920	5.675	5.500	5.275	5.200	5.150
1.330	.....	6.200	6.000	5.730	5.550	5.350	5.250	5.220

TABLE 27 (*Concluded*)

DISCHARGE IN CUBIC FEET PER SECOND PER FOOT OF LENGTH OF WEIR

Head, in Feet	Weir 0.5 Ft. High	Weir 0.75 Ft. High	Weir 1.00 Ft. High	Weir 1.50 Ft. High	Weir 2.00 Ft. High	Weir 3.00 Ft. High	Weir 4.00 Ft. High	Weir 6.00 Ft. High
1.340	.....	6.300	6.050	5.800	5.620	5.400	5.320	5.260
1.350	.....	6.375	6.130	5.875	5.675	5.460	5.370	5.320
1.360	.....	6.450	6.200	5.940	5.750	5.520	5.430	5.380
1.370	.....	6.505	6.300	6.000	5.820	5.580	5.500	5.450
1.380	.....	6.625	6.375	6.080	5.900	5.650	5.560	5.525
1.390	.....	6.700	6.450	6.150	5.960	5.725	5.625	5.575
1.400	.....	6.780	6.530	6.230	6.040	5.770	5.675	5.640
1.410	.....	6.860	6.620	6.320	6.100	5.850	5.760	5.700
1.420	.....	6.950	6.675	6.375	6.150	5.920	5.820	5.760
1.430	.....	7.000	6.750	6.450	6.220	5.975	5.875	5.825
1.440	.....	7.075	6.820	6.520	6.300	6.030	5.930	5.880
1.450	.....	7.150	6.900	6.600	6.360	6.100	6.000	5.950
1.460	.....	7.250	6.975	6.660	6.430	6.150	6.050	6.000
1.470	.....	7.330	7.050	6.740	6.500	6.220	6.120	6.060
1.480	.....	7.400	7.130	6.800	6.508	6.300	6.175	6.125
1.490	.....	7.480	7.200	6.850	6.640	6.330	6.230	6.160
1.500	.....	7.600	7.300	6.950	6.720	6.420	6.300	6.250
1.510	.....	7.660	7.360	7.020	6.775	6.500	6.360	6.300
1.520	.....	7.750	7.450	7.100	6.850	6.550	6.450	6.360
1.530	.....	7.825	7.520	7.160	6.930	6.640	6.520	6.460
1.540	.....	7.900	7.600	7.230	7.000	6.680	6.575	6.500
1.550	.....	7.980	7.660	7.300	7.040	6.740	6.625	6.560
1.560	.....	8.075	7.730	7.400	7.120	6.800	6.700	6.630
1.570	.....	8.150	7.820	7.450	7.180	6.860	6.740	6.680
1.580	.....	8.250	7.900	7.525	7.250	6.940	6.800	6.750
1.590	.....	8.300	7.960	7.560	7.300	6.975	6.850	6.780

Table 28 gives the discharge per foot of length over sharp-crested vertical weirs, without end contractions, of heights 2, 4, 6, 8, 10, 20, and 30 feet, computed from Bazin's formula. Although this formula is based on data obtained from experiments with heads not greater than 1.64 feet, discharges for heads of 4 feet and less computed thereby agree within 2 per cent with those obtained by use of the Fteley and Stearns formula. The discharge given by this table is corrected for velocity of approach, and the head to be used is that observed 16 feet or more upstream from the crest of the weir.

TABLE 28

DISCHARGE PER FOOT OF LENGTH OVER SHARP-CRESTED VERTICAL WEIRS WITHOUT END CONTRACTIONS *

[Computed from the formula $Q = \left(0.405 + \frac{.00984}{h}\right)\left(1 + 0.55\frac{h^2}{(p+h)^2}\right) Lh\sqrt{2gh}$ (h = observed head, in feet; p = height of weir, in feet; L = length of crest, in feet; Q = discharge, in second-feet.)]

h \ p	2	4	6	8	10	20	30
0.1	0.13	0.13	0.13	0.13	0.13	0.13	0.13
0.2	.33	.33	.33	.33	.33	.33	.33
0.3	.58	.58	.58	.58	.58	.58	.58
0.4	.88	.88	.87	.87	.87	.87	.87
0.5	1.23	1.21	1.21	1.21	1.21	1.20	1.20
0.6	1.62	1.59	1.58	1.58	1.57	1.57	1.57
0.7	2.04	1.99	1.98	1.98	1.97	1.97	1.97
0.8	2.50	2.43	2.41	2.41	2.40	2.40	2.40
0.9	3.00	2.90	2.88	2.86	2.86	2.85	2.85
1.0	3.53	3.40	3.36	3.35	3.34	3.33	3.33
1.1	4.10	3.93	3.88	3.86	3.85	3.84	3.83
1.2	4.69	4.48	4.42	4.40	4.38	4.36	4.36
1.3	5.32	5.07	4.99	4.96	4.94	4.92	4.91
1.4	5.99	5.68	5.58	5.55	5.52	5.49	5.48
1.5	6.69	6.30	6.20	6.16	6.13	6.08	6.07
1.6	7.40	6.97	6.84	6.78	6.75	6.69	6.68
1.7	8.15	7.66	7.50	7.43	7.39	7.33	7.31
1.8	8.93	8.37	8.18	8.09	8.05	7.98	7.96
1.9	9.74	9.11	8.89	8.79	8.74	8.65	8.63
2.0	10.58	9.87	9.62	9.51	9.44	9.34	9.32
2.1	11.44	10.65	10.37	10.24	10.17	10.05	10.02
2.2	12.33	11.46	11.14	10.99	10.91	10.78	10.75
2.3	13.25	12.29	11.93	11.77	11.67	11.52	11.48
2.4	14.20	13.15	12.75	12.56	12.45	12.28	12.24
2.5	15.18	14.03	13.59	13.37	13.25	13.06	13.02
2.6	16.17	14.92	14.44	14.20	14.07	13.85	13.80
2.7	17.19	15.84	15.31	15.05	14.90	14.65	14.60
2.8	18.23	16.79	16.21	15.92	15.76	15.48	15.42
2.9	19.29	17.75	17.12	16.81	16.63	16.32	16.25
3.0	20.38	18.74	18.06	17.71	17.52	17.18	17.10
3.1	21.50	19.74	19.01	18.64	18.42	18.05	17.96
3.2	22.64	20.77	19.98	19.58	19.34	18.93	18.83
3.3	23.80	21.82	20.98	20.54	20.28	19.83	19.72
3.4	24.98	22.89	21.99	21.52	21.24	20.75	20.63
3.5	26.20	23.98	23.01	22.51	22.22	21.69	21.55
3.6	27.42	25.09	24.06	23.52	23.20	22.62	22.48
3.7	28.67	26.23	25.13	24.55	24.21	23.58	23.43
3.8	29.94	27.38	26.22	25.60	25.23	24.56	24.39
3.9	31.23	28.55	27.32	26.66	26.27	25.54	25.37
4.0	32.54	29.74	28.45	27.74	27.32	26.55	26.35
4.1	33.87	30.96	29.59	28.84	28.39	27.56	27.34
4.2	35.22	32.18	30.75	29.96	29.48	28.59	28.35
4.3	36.59	33.43	31.92	31.09	30.58	29.63	29.38
4.4	37.99	34.70	33.12	32.24	31.70	30.68	30.42

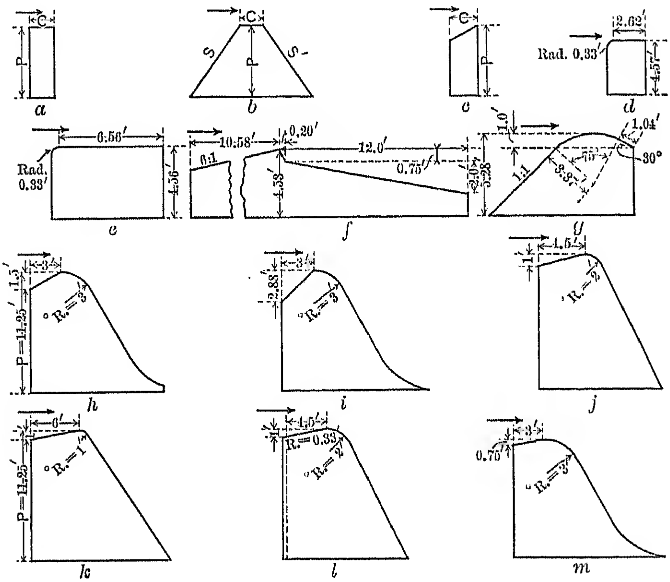
* This table should not be used where the weir is submerged, nor unless the overfalling sheet is aerated on the downstream face of the weir. If a vacuum forms under the falling sheet the discharge may be 5 per cent greater than given in this table.

TABLE 28 (*Concluded*)

DISCHARGE PER FOOT OF LENGTH OVER SHARP-CRESTED VERTICAL WEIRS WITHOUT END CONTRACTIONS

h \ p	2	4	6	8	10	20	30
4.5	39.40	35.98	34.33	33.40	32.83	31.74	31.47
4.6	40.83	37.29	35.56	34.58	33.98	32.82	32.53
4.7	42.28	38.61	36.80	35.78	35.14	33.92	33.61
4.8	43.75	39.96	38.07	37.00	36.32	35.04	34.70
4.9	45.23	41.32	39.35	38.23	37.52	36.17	35.80
5.0	46.73	42.69	40.65	39.48	38.74	37.21	36.91
5.1	48.25	44.09	41.96	40.73	39.97	38.45	38.03
5.2	49.79	45.50	43.29	42.01	41.20	39.61	39.17
5.3	51.36	46.93	44.64	43.30	42.45	40.78	40.31
5.4	52.94	48.38	46.00	44.60	43.71	41.96	41.47
5.5	54.54	49.85	47.38	45.93	45.00	43.16	42.64
5.6	56.15	51.34	48.79	47.27	46.31	44.38	43.83
5.7	57.78	52.83	50.19	48.62	47.62	45.60	45.02
5.8	59.42	54.34	51.62	49.99	48.94	46.83	46.22
5.9	61.09	55.88	53.07	51.38	50.29	48.08	47.44
6.0	62.77	57.43	54.53	52.78	51.64	49.34	48.67
6.1	64.46	59.00	56.00	54.20	53.02	50.61	49.91
6.2	66.18	60.58	57.50	55.63	54.40	51.90	51.16
6.3	67.91	62.18	59.01	57.07	55.80	53.20	52.42
6.4	69.65	63.79	60.53	58.53	57.22	54.50	53.70
6.5	71.42	65.42	62.07	60.01	58.65	55.82	54.98
6.6	73.19	67.07	63.63	61.50	60.09	57.16	56.27
6.7	74.99	68.74	65.20	63.00	61.55	58.50	57.58
6.8	76.80	70.42	66.78	64.53	63.02	59.96	58.90
6.9	78.62	72.11	68.38	66.06	64.50	61.23	60.22
7.0	80.46	73.82	70.00	67.60	66.00	62.61	61.56
7.1	82.32	75.55	71.63	69.17	67.52	64.00	62.91
7.2	84.18	77.29	73.28	70.74	69.04	65.40	64.27
7.3	86.07	79.04	74.94	72.34	70.58	66.81	65.64
7.4	87.97	80.81	76.61	73.94	72.14	68.24	67.02
7.5	89.89	82.60	78.30	75.56	73.70	69.68	68.41
7.6	91.82	84.40	80.01	77.19	75.28	71.13	69.81
7.7	93.76	86.22	81.73	78.84	76.88	72.59	71.23
7.8	95.72	88.05	83.46	80.50	78.48	74.06	72.65
7.9	97.70	89.90	85.21	82.18	80.11	75.55	74.09
8.0	99.68	91.75	86.97	83.87	81.74	77.04	75.53
8.1	101.69	93.63	88.75	85.57	83.39	78.55	76.98
8.2	103.70	95.51	90.54	87.29	85.25	80.06	78.44
8.3	105.73	97.42	92.34	89.02	86.72	81.59	79.92
8.4	107.78	99.34	94.16	90.76	88.41	83.13	81.40
8.5	109.84	101.27	96.00	92.52	90.11	84.69	82.90
8.6	111.91	103.21	97.84	94.29	91.82	86.25	84.41
8.7	113.99	105.17	99.70	96.07	93.55	87.82	85.92
8.8	116.09	107.14	101.57	97.87	95.28	89.40	87.44
8.9	118.20	109.13	103.46	99.68	97.04	91.00	88.98
9.0	120.33	111.13	105.36	101.50	98.80	92.61	90.52
9.1	122.47	113.15	107.28	103.34	100.58	94.23	92.08
9.2	124.62	115.18	109.21	105.19	102.37	95.86	93.65
9.3	126.79	117.22	111.15	107.06	104.17	97.49	95.22
9.4	128.97	119.27	113.10	108.93	105.99	99.14	96.80
9.5	131.16	121.34	115.07	110.82	107.82	100.80	98.40
9.6	133.36	123.42	117.05	112.72	109.65	102.48	100.00
9.7	135.58	125.51	119.04	114.64	111.50	104.16	101.62
9.8	137.82	127.63	121.05	116.57	113.37	105.85	103.25
9.9	140.06	129.74	123.07	118.51	115.25	107.56	104.88
10.0	142.31	131.87	125.10	120.46	117.14	109.27	106.52

Tables 28A, 28B, and 28C give multipliers to be applied to quantities in Table 28 to determine the discharge over broad-crested weirs of various types and dimensions. Example: Sup-



pose the discharge is to be computed over a rectangular weir that is 10 feet long, 12 feet high, 6 feet crest width, and has an observed head of 2.4 feet. Table 28 shows that for a height (p) of 12 feet and a head (h) of 2.4, the discharge is 12.42 second-feet. Table 28A shows that for a height (p) of 12 feet, a crest width (c) of 6 feet, and head (h) of 2.4 feet the multiplier is 0.797. Hence, the discharge is $12.42 \times 0.797 \times 10 = 99.0$ second-feet.

TABLE 28A

Multipliers of Discharge Over Rectangular Weir, Broad-Crested (Type *a*, See Figure)

[p = height of weir; c = width of crest; h = observed head; all in feet]

p / c	4.6 / 2.6	4.6 / 6.6	11.25 / .48	11.25 / .93	11.25 / 1.65	11.25 / 3.17	11.25 / 5.88	11.25 / 8.98	11.25 / 12.24	11.25 / 16.30
h										
0.5	....	....	.821	.792	.806	.792	.799	.801	.786	.790
1.0	.765	.708	.997	.899	.808	.795	.791	.794	.815	.790
1.5	.789	.709	1.00	.982	.878	.796	.796	.793	.814	.792
2.0	.814	.710	1.00	1.00	.906	.815	.797	.792	.797	.793
2.5	.835	.711	1.00	1.00	.985	.844	.797	.790	.796	.793
3.0	.857	.711	1.00	1.00	1.00	.870	.797	.788	.794	.791
3.5	.878	.712	1.00	1.00	1.00	.90	.812	.787	.794	.791
4.0	.899	.714	1.00	1.00	1.00	.93	.834	.786	.792	.789
5.0	.940	.716	1.00	1.00	1.00	.97	(*a*)	.78	.79	.78
6.0	.986	.718	1.00	1.00	1.00	.98	(*a*)	.78	.78	.78
7.0	....	....	1.00	1.00	1.00	(*a*)	(*a*)	.77	.78	.77
8.0	....	....	1.00	1.00	1.00	(*a*)	(*a*)	.77	.77	.77
9.0	....	....	1.00	1.00	1.00	(*a*)	(*a*)	.77	.77	.77
10.0	....	....	1.00	1.00	1.00	(*a*)	(*a*)	.77	.77	.77

(*a*) Value doubtful.

TABLE 28B

Multipliers of Discharge for Trapezoidal Weirs

[p = height of weir, in feet; c = width of crest, in feet; s = upstream slope; s' = downstream slope; h = observed head, in feet]

	Type *b* (see Figure)							Type *c* (see Figure)	
p / c / s / s'	4.9 / .33 / 2:1 / 0	4.9 / .66 / 2:1 / 0	4.9 / .66 / 3:1 / 0	4.9 / .66 / 4:1 / 0	4.9 / .66 / 5:1 / 0	4.9 / .33 / 2:1 / 5:1	4.9 / .66 / 2:1 / 2:1	4.65 / 7.00 / 4.67:1 /	11.25 / 6.00 / 6:1 / ......
h									
1.0	1.137	1.048	1.066	1.039	1.009	1.095	1.071	1.042	1.060
1.5	1.131	1.068	1.066	1.039	1.009	1.071	1.066	1.033	1.069
2.0	1.120	1.080	1.061	1.033	1.005	1.044	1.053	1.024	1.054
2.5	1.106	1.085	1.052	1.026	.997	1.024	1.047	1.012	1.012
3.0	1.094	1.088	1.047	1.020	.991	1.009	1.047	.995	.985
3.5	1.085	1.087	1.043	1.017	.988	1.003	1.050	.983	.979
4.0	1.072	1.084	1.038	1.012	.984	1.014	1.052	.977	.976
4.5	1.064	1.081	1.035	1.009	.980	1.023	1.055	.974	.973
5.0	.....	.....	.....	.....	.....	.....	.....	.97	.97
6.0	.....	.....	.....	.....	.....	.....	.....	.97	.96
7.0	.....	.....	.....	.....	.....	.....	.....	.97	.96
8.0	.....	.....	.....	.....	.....	.....	.....	.96	.95
9.0	.....	.....	.....	.....	.....	.....	.....	.96	.95
10.0	.....	.....	.....	.....	....	.....	.....	.96	.95

TABLE 28C

Multipliers of Discharge for Compound Weirs

[p = height of weir, in feet; h = observed head, in feet]

p	4.57	4.56	4.53	5.28	11.25	11.25	11.25	11.25	11.25	11.25
Type (see Figure)	*d*	*e*	*f*	*g*	*h*	*i*	*j*	*k*	*l*	*m*
h										
0.5	....	....	....	....	.941	.924	.933	.962	.971	.947
1.0	.842	.836	.929	.976	1.039	1.033	.988	1.045	1.033	1.000
1.5	.866	.834	.950	.979	1.087	1.093	1.018	1.066	1.042	1.036
2.0	.888	.831	.953	.988	1.109	1.133	1.033	1.063	1.035	1.063
2.5	.906	.826	.947	1.000	1.118	1.153	1.045	1.020	1.033	1.085
3.0	.927	.822	.942	1.016	1.120	1.163	1.054	.997	1.045	1.096
3.5	.945	.817	.936	1.032	1.127	1.169	1.060	.994	1.054	1.108
4.0	.965	.812	.931	1.044	1.123	1.165	1.060	.991	1.057	1.110
5.0	1.00	.80	.92	1.05	1.11	1.16	1.05	.98	1.05	1.10
6.0	....	....	....	....	1.11	1.15	1.04	.98	1.04.	1.10
7.0	....	....	....	....	1.10	1.14	1.04	.97	1.04	1.09
8.0	....	....	....	....	1.10	1.14	1.04	.97	1.03	1.09
9.0	....	....	....	....	1.09	1.14	1.03	.97	1.03	1.08
10.0	....	....	....	....	1.09	1.13	1.03	.97	1.03	1.08

TABLE 29

Acre-feet Equivalent to a Given Number of Second-feet Flowing for a Given Length of Time

Second-Feet	Days of 24 Hours									
	1	2	3	4	5	6	7	8	9	10
0.01	0.0198	.0396	0.0595	.0793	.0991	.1190	.1388	.1586	.1785	.1983
.02	.0396	.0793	.1190	.1586	.1983	.2380	.2776	.3173	.3570	.3966
.03	.0595	.1190	.1785	.2380	.2975	.3570	.4165	.4760	.5355	.5950
.04	.0793	.1586	.2330	.3173	.3966	.4760	.5553	.6347	.7140	.7933
.05	.0991	.1983	.2975	.3966	.4958	.5950	.6942	.7933	.8925	.9917
.06	.1190	.2380	.3570	.4760	.5950	.7140	.8330	.9520	1.071	1.190
.07	.1388	.2776	.4165	.5553	.6942	.8330	.9719	1.110	1.249	1.388
.08	.1586	.3173	.4760	.6347	.7933	.9520	1.110	1.269	1.423	1.586
.09	.1785	.3570	.5355	.7140	.8925	1.071	1.249	1.428	1.606	1.785
.10	.1983	.3966	.5950	.7933	.9917	1.190	1.388	1.586	1.785	1.983
.11	.2181	.4363	.6545	.8727	1.090	1.309	1.527	1.745	1.963	2.181
.12	.2380	.4760	.7140	.9520	1.190	1.428	1.666	1.904	2.142	2.380
.13	.2578	.5157	.7735	1.031	1.289	1.547	1.804	2.022	2.320	2.578
.14	.2776	.5553	.8330	1.110	1.388	1.666	1.943	2.221	2.499	2.776
.15	.2975	.5950	.8925	1.190	1.487	1.785	2.082	2.380	2.677	2.975
.16	.3173	.6347	.9520	1.269	1.586	1.904	2.221	2.538	2.856	3.173
.17	.3371	.6743	1.011	1.343	1.685	2.023	2.360	2.697	2.034	3.371
.18	.3570	.7140	1.071	1.428	1.785	2.142	2.499	2.856	3.213	3.570
.19	.3768	.7537	1.130	1.507	1.884	2.261	2.638	3.014	3.391	3.768
.20	.3966	.7933	1.190	1.586	1.983	2.380	2.776	3.173	3.570	3.966
.21	.4165	.8330	1.249	1.666	2.082	2.499	2.915	3.332	3.748	4.165
.22	.4363	.8727	1.309	1.745	2.181	2.618	3.054	3.490	3.927	4.363
.23	.4562	.9124	1.368	1.824	2.280	2.737	3.193	3.649	4.105	4.561
.24	.4760	.9520	1.428	1.904	2.380	2.856	3.332	3.808	4.284	4.760
.25	.4958	.9917	1.487	1.983	2.479	2.975	3.471	3.966	4.462	4.958
.26	.5157	1.031	1.547	2.062	2.578	3.094	3.609	4.125	4.641	5.157
.27	.5355	1.071	1.606	2.142	2.677	3.213	3.748	4.284	4.819	5.355
.28	.5553	1.110	1.666	2.221	2.776	3.332	3.887	4.442	4.998	5.553
.29	.5752	1.150	1.725	2.300	2.876	3.451	4.026	4.601	5.176	5.752
.30	.5950	1.190	1.785	2.380	2.975	3.570	4.165	4.760	5.355	5.950
.31	.6148	1.229	1.844	2.459	3.074	3.689	4.304	4.919	5.533	6.143
.32	.6347	1.269	1.904	2.538	3.173	3.808	4.442	5.077	5.712	6.347
.33	.6545	1.309	1.963	2.618	3.272	3.927	4.581	5.236	5.890	6.545
.34	.6743	1.348	2.023	2.697	3.371	4.046	4.720	5.395	6.069	6.743
.35	.6942	1.388	2.082	2.776	3.471	4.165	4.859	5.553	6.247	6.942
.36	.7140	1.428	2.142	2.856	8.570	4.284	4.998	5.712	6.426	7.140
.37	.7338	1.467	2.201	2.935	3.669	4.403	5.137	5.871	6.604	7.338
.38	.7537	1.507	2.261	3.014	3.768	4.522	5.276	6.029	6.783	7.537
.39	.7735	1.547	2.320	3.094	3.867	4.641	5.414	6.188	6.961	7.735
.40	.7933	1.586	2.380	3.173	3.966	4.760	5.553	6.347	7.140	7.933
.41	.8132	1.626	2.439	3.252	4.066	4.879	5.692	6.505	7.319	8.132
.42	.8330	1.666	2.499	3.332	4.165	4.998	5.831	6.664	7.497	8.330
.43	.8528	1.705	2.558	3.411	4.264	5.117	5.970	6.823	7.676	8.528
.44	.8727	1.745	2.618	3.490	4.363	5.236	6.109	6.981	7.854	8.727
.45	.8925	1.785	2.677	3.570	4.462	5.355	6.247	7.140	8.033	8.925
.46	.9124	1.824	2.737	3.649	4.561	5.474	6.386	7.299	8.211	9.123
.47	.9322	1.864	2.796	3.728	4.661	5.593	6.525	7.457	8.390	9.322
.48	.9520	1.904	2.856	3.808	4.760	5.712	6.664	7.616	8.568	9.520
.49	.9719	1.943	2.915	3.887	4.859	5.831	6.803	7.775	8.747	9.719
0.50	0.9917	1.983	2.975	3.966	4.958	5.950	6.942	7.933	8.925	9.917

NOTE.—For larger quantities and greater number of days than given in this table it is only necessary to move the decimal point, thus, for .25 c. f. s. flowing six days we read the equivalent 2.975 acre-feet and for 25 c. f. s. the equivalent in acre-feet is 297.5. Again, .25 c. f. s. flowing sixty days = 29.75 acre-feet and 25 c. f. s. flowing sixty days = 2975 acre-feet, etc., etc.

TABLE 29 (*Concluded*)

Acre-feet Equivalent to a Given Number of Second-feet Flowing for a Given Length of Time

Second-Feet	Days of 24 Hours									
	1	2	3	4	5	6	7	8	9	10
0.51	1.011	2.023	3.034	4.046	5.057	6.069	7.080	8.092	9.104	10.115
.52	1.031	2.062	3.094	4.125	5.157	6.188	7.219	8.251	9.282	10.314
.53	1.051	2.102	3.153	4.204	5.256	6.307	7.358	8.409	9.461	10.519
.54	1.071	2.142	3.213	4.284	5.355	6.426	7.497	8.568	9.639	10.710
.55	1.090	2.181	3.272	4.363	5.454	6.545	7.636	8.727	9.818	10.909
.56	1.110	2.221	3.332	4.442	5.553	6.664	7.775	8.885	9.996	11.107
.57	1.130	2.261	3.391	4.522	5.652	6.783	7.914	9.044	10.175	11.305
.58	1.150	2.300	3.451	4.601	5.752	6.902	8.052	9.203	10.353	11.504
.59	1.170	2.340	3.510	4.680	5.851	7.021	8.191	9.361	10.532	11.702
.60	1.190	2.380	3.570	4.760	5.950	7.140	8.330	9.520	10.710	11.900
.61	1.209	2.419	3.629	4.839	6.049	7.259	8.469	9.679	10.889	12.099
.62	1.229	2.459	3.689	4.919	6.143	7.378	8.608	9.838	11.067	12.297
.63	1.249	2.499	3.748	4.998	6.247	7.497	8.747	9.996	11.246	12.495
.64	1.269	2.538	3.808	5.077	6.347	7.616	8.885	10.155	11.424	12.694
.65	1.289	2.578	3.867	5.157	6.446	7.735	9.024	10.314	11.603	12.892
.66	1.309	2.618	3.927	5.236	6.545	7.854	9.163	10.472	11.781	13.090
.67	1.328	2.657	3.986	5.315	6.644	7.973	9.302	10.631	11.960	13.289
.68	1.348	2.697	4.046	5.395	6.743	8.092	9.441	10.790	12.138	13.487
.69	1.368	2.737	4.105	5.474	6.842	8.211	9.580	10.948	12.317	13.685
.70	1.388	2.776	4.165	5.553	6.942	8.330	9.719	11.107	12.495	13.884
.71	1.408	2.816	4.224	5.633	7.041	8.449	9.857	11.266	12.674	14.082
.72	1.428	2.856	4.284	5.712	7.140	8.568	9.996	11.424	12.852	14.280
.73	1.447	2.895	4.348	5.791	7.239	8.687	10.135	11.583	13.031	14.479
.74	1.467	2.935	4.403	5.871	7.338	8.806	10.274	11.742	13.209	14.677
.75	1.487	2.975	4.462	5.950	7.438	8.925	10.413	11.900	13.388	14.876
.76	1.507	3.014	4.522	6.029	7.537	9.044	10.552	12.059	13.566	15.074
.77	1.527	3.054	4.581	6.109	7.636	9.163	10.690	12.218	13.745	15.272
.78	1.547	3.094	4.641	6.188	7.735	9.282	10.829	12.376	13.923	15.471
.79	1.566	3.133	4.700	6.267	7.834	9.401	10.968	12.535	14.102	15.669
.80	1.586	3.173	4.760	6.347	7.933	9.520	11.107	12.694	14.280	15.867
.81	1.606	3.213	4.819	6.426	8.033	9.639	11.246	12.852	14.459	16.066
.82	1.626	3.252	4.879	6.505	8.132	9.758	11.385	13.011	14.638	16.264
.83	1.646	3.292	4.938	6.585	8.231	9.877	11.523	13.170	14.816	16.462
.84	1.666	3.332	4.998	6.664	8.330	9.996	11.662	13.328	14.995	16.661
.85	1.685	3.371	5.057	6.743	8.429	10.115	11.801	13.487	15.173	16.859
.86	1.705	3.411	5.117	6.823	8.528	10.234	11.940	13.646	15.352	17.057
.87	1.725	3.451	5.176	6.902	8.628	10.358	12.079	13.804	15.530	17.256
.88	1.745	3.490	5.236	6.981	8.727	10.472	12.218	13.963	15.709	17.454
.89	1.765	3.530	5.295	7.061	8.826	10.591	12.357	14.122	15.887	17.652
.90	1.785	3.570	5.355	7.140	8.925	10.710	12.495	14.280	16.066	17.851
.91	1.804	3.609	5.414	7.219	9.024	10.829	12.634	14.439	16.244	18.049
.92	1.824	3.649	5.474	7.299	9.123	10.948	12.773	14.598	16.423	18.247
.93	1.844	3.689	5.533	7.378	9.223	11.067	12.912	14.757	16.601	18.446
.94	1.864	3.728	5.593	7.457	9.322	11.186	13.051	14.915	16.780	18.644
.95	1.884	3.768	5.652	7.537	9.421	11.305	13.190	15.074	16.958	18.842
.96	1.904	3.808	5.712	7.616	9.520	11.424	13.328	15.233	17.137	19.041
.97	1.923	3.847	5.771	7.695	9.619	11.543	13.467	15.391	17.315	19.239
.98	1.943	3.887	5.831	7.775	9.719	11.662	13.606	15.550	17.494	19.438
.99	1.963	3.927	5.890	7.854	9.818	11.781	13.745	15.709	17.672	19.636
1.00	1.983	3.966	5.950	7.933	9.917	11.900	13.884	15.867	17.851	19.834

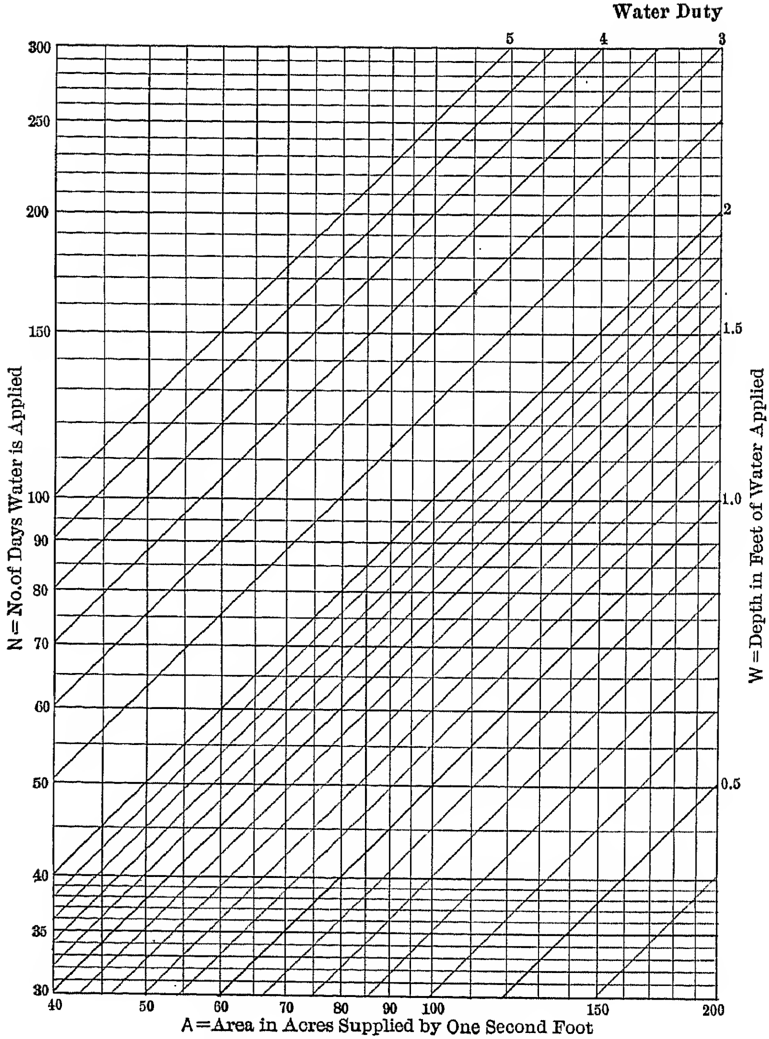


FIG. 38.—Diagram for Converting "Acres per Second-foot" to "Depth of Water Applied in Given Length of Time," $W = \frac{1.9835\,N}{A}$

TABLE 30

LIST OF HYDRAULIC FORMULAS

Index No.	Formula	Subject	Remarks
1	$V = \sqrt{2gh} = 8.02\sqrt{h}$	Theoretical velocity of water due to head h.	
2	$h = \frac{V^2}{2g} = .01555\,V^2$	Theoretical velocity head.	
3	$h_1 = \frac{V_2^2 - V_1^2}{2g}$	Head required to increase velocity from V_1 to V_2.	
4	$h_e = K\frac{V^2}{2g}$	Loss of head at entrance to pipes, flumes, etc. (not including velocity head).	$K = 1 - C^2$ (C = coeff. of discharge) Approximate values of K: $K = 0.50$ for square edges or square wing walls. $K = 0.25$ for rounded edges or flaring wingwalls. $K = 0.05$ for bell mouths or very smooth transition.
5	$V = C_1\sqrt{2gh}$	Velocity of water issuing from an orifice.	C_1 varies from about .97 to .99. Average value .98. For a free orifice h = head on center of orifice and for a submerged orifice h = difference in elevation of water surface above and below.
6	$Q = CA\sqrt{2gh}$	Discharge of "standard" orifice free or submerged.	A = area of opening. C varies from about .60 to .63, the mean value being about .62. For free orifices this formula is accurate for all heads on center of orifice greater than twice the depth of the orifice.

TABLE 30—(*Continued*)

LIST OF HYDRAULIC FORMULAS

Index No.	Formula	Subject	Remarks
			For submerged orifices h = difference in elevation of water surface above and below orifice and the formula is accurate for all heads.
7	$Q = C b \sqrt{2g}\,(h_2^{3/2} - h_1^{3/2})$	Exact discharge of square or rectangular "standard" orifice, free.	b = width of orifice. h_2 = head on bottom. h_1 = head on top. C varies as above noted.
8	$Q = 3.33\, L H^{3/2}$	Francis formula for discharge of suppressed rectangular weirs.	L = length of crest. H = head on crest measured a short distance above the plane of the weir.
9	$Q = 3.33\, H^{3/2}(L - 0.2\,H)$	Francis formula for discharge of contracted rectangular weir.	
10	$Q = 3.37\, L H^{3/2}$	Discharge of Cippoletti weir.	
11	$Q = 2.54\, H^{5/2}$	Discharge of triangular weir with an angle of 90° at apex.	
12	$Q = 3.33\, L\,[(H + h)^{3/2} - h^{3/2}]$	Francis formula for suppressed weirs corrected for velocity of approach.	h = velocity head.
13	$Q = 3.33\,(L - 0.2\,H)\,[(H + h)^{3/2} - h^{3/2}]$	Francis formula for contracted rectangular weirs, corrected for velocity of approach.	Do.
14	$Q = \left(.405 + \frac{.00984}{H}\right)\left(1 + .55\,\frac{H^2}{(p + H)^2}\right)\sqrt{2\,g}\,L\,H^{3/2}$	Bazin's formula for suppressed rectangular weir.	p = height of weir crest above floor of approach channel. This formula automatically corrects for velocity of approach.
15	$H_1 = H + \frac{V^2}{2g}$	Approximate corrected head when velocity of approach V exists.	For use with weirs and orifices.
16	$V = C\sqrt{R\,S}$	Chezy formula for velocity in open channels.	R = hydraulic mean radius.

17	$C = \dfrac{\dfrac{1.811}{n} + 41.6 + \dfrac{.00281}{s}}{1 + \left(41.6 + \dfrac{.00281}{s}\right)\dfrac{n}{\sqrt{R}}}$	Kutter's formula for C in Chezy formula.	S = sine of slope. C = empirical coefficient. n varies from about .010 for the smoothest channels to about .035 for the roughest artificial channels and to about .060 for the roughest natural channels.
18	$Q = 0.1\, D^2 \sqrt{\dfrac{D\,H}{f}}$	Fanning's formula for discharge of iron pipes (modified).	D = diameter in feet. H = friction loss in 1,000 feet. For new pipes f varies from .0071 when $V = 1$ to .0028 when $V = 10$.
19	$Q = 1.35\, D^{2.7}\, H^{.555}$	Author's formula for discharge of wood stave pipe.	D = diameter in feet. H = friction loss in 1,000 feet. Q = discharge in c. f. s.
20	$Q = 1.31\, D^{2.7}\, H^{.555}$	Author's formula for new asphalted cast-iron pipe.	
21	$Q = 1.24\, D^{2.7}\, H^{.555}$	Author's formula for smooth concrete pipe.	
22	$Q = 1.18\, D^{2.7}\, H^{.555}$	Author's formula for new asphalted riveted steel pipe.	
23	$y = \dfrac{g\,x^2}{2\,V^2} = \dfrac{x^2}{4\,h}$	Path of a jet issuing horizontally.	x = horizontal distance from plane of issue. In the case of an orifice y is measured from the center of orifice. In the case of a stream discharging from the end of a flume y is measured from the point where V is measured.
24	$y = x \tan\theta - \dfrac{x^2 \sec^2\theta}{4\,h}$	Path of a jet issuing at an angle θ with the horizontal.	
25	$E = \dfrac{W\,V^2}{2\,g}$	Energy of a jet or other moving body of water.	W = wt. of water passing a given cross-section per second of time.
26	$V = 0.8\, V_1$	Formula commonly used for reduction of max. surface to mean velocity in open channels.	V_1 = surface velocity. The coeff. is difficult to determine and probably varies from about 0.7 to 0.9 for different conditions.

TABLE 30—(*Concluded*)

LIST OF HYDROSTATIC FORMULAS

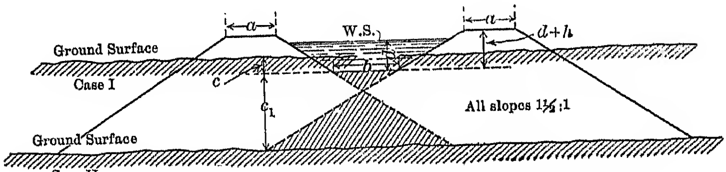
Index No.	Formula	Subject	Remarks
A	$p = .434\ h$	Pressure of water in pounds per square inch under a head of h feet.	
B	$P = 62.5\ h$	Pressure of water in pounds per square foot at a depth h below surface.	
C	$P = 31.25\ h^2$	Total horizontal pressure in pounds on a body one foot wide, having its top at or above the surface and its bottom h feet below the surface.	
D	$P = 31.25\ (h^2 - h_1^2)$	Total horizontal pressure on the same body when its top is submerged h_1 feet below the surface.	

CHAPTER V
STRUCTURAL DIAGRAMS AND TABLES

CHAPTER V

STRUCTURAL DIAGRAMS AND TABLES

Fig. 39 gives the volume of excavation and embankment in cubic yards per 100 feet for small canals in ground which is level transversely. In deriving the equations for volume of embankment two cases must be considered: Case I, where the bed of canal is below the ground surface; and Case II, where



TYPICAL SECTIONS

the bed of canal is above the ground surface. The two cases are illustrated in the accompanying figure.

Case I.—

Equations: Cut $V = 3.7\,(b\,c + 1.5\,c^2)$, in cubic yds. per 100 ft.

$$\text{Fill} \quad V_1 = 7.4\left[a(d + h - c) + 1.5\,(d + h - c)^2\right]$$

Example: Assume $b = 3$

$c = 2$

$a = 2$

$d + h = 3$

Enter the diagram with these arguments and read directly—cut $V = 44$ cubic yards. To get the "fill," enter the diagram at $c = 2$, follow the diagonal line from this point to its intersection with the vertical line marked $d + h = 3$; thence horizontally to the right to the curve marked "$a = 2$" and read on the upper scale $V_1 = 26$. The cut in this case exceeds the fill, and the former is, therefore, the controlling factor. For a cut c of 1 foot the excavation is found to be 13 cubic yards and the fill 73

cubic yards. In this case the fill is the controlling factor, as it exceeds the cut by 60 cubic yards.

Case II.—In this case the canal is entirely in fill, and two quantities must be looked out from the diagram to make up the total fill. In calculating fills, the simplest process is to calculate the sum of the two embankments considered as full trapezoidal sections with bases "a." Referring to the diagram, it will be seen that for the condition there represented as "Case II," we must deduct from the total quantity thus obtained the volume of the lower shaded triangular prism, and add the volume of the upper shaded triangular prism. The algebraic sum of these two triangular prisms may be either positive, negative, or zero, depending upon whether the upper prism is greater than, less than, or equal to the lower prism. The general equation for this sum is $E = -.617\left[(3\,c_1 - b)^2 - b^2\right]$. The plot of this equation on the diagram shows the *positive* values of E on the left of the vertical axis, *negative* values on the right, and zero values at the intersection of curves with the vertical axis. The complete equation for embankment in Case II is:

Total volume

$$= V_1 + E = 7.4\left[a\,(d + h + c_1) + 1.5\,(d + h + c_1)^2\right] - 0.617\left[(3\,c_1 - b)^2 - b^2\right]$$

Example: Assume

$$b = 2$$
$$c_1 = 2$$
$$d + h = 2$$
$$a = 2$$

To get V_1, enter the diagram at $c_1 = 2$ or $c = -2$; thence follow the diagonal line to $d + h = 2$; thence horizontally to the right to the curve marked $a = 2$ and read on the lower scale $V_1 = 237$ *c.y.* Now to get E, enter the diagram at the same point, $c_1 = 2$; thence horizontally to the right to the curve for E marked $b = 2$ and read -8 *c.y.* The net fill, then, is $V_1 + E = 237 - 8 = 229$ *c.y.*

If $b = 3$ and the other factors remain the same, $E =$ zero, and if $b = 3.5$, $E = +4$, the value of V_1 remaining the same in all three cases, as it is independent of the bottom width of canal.

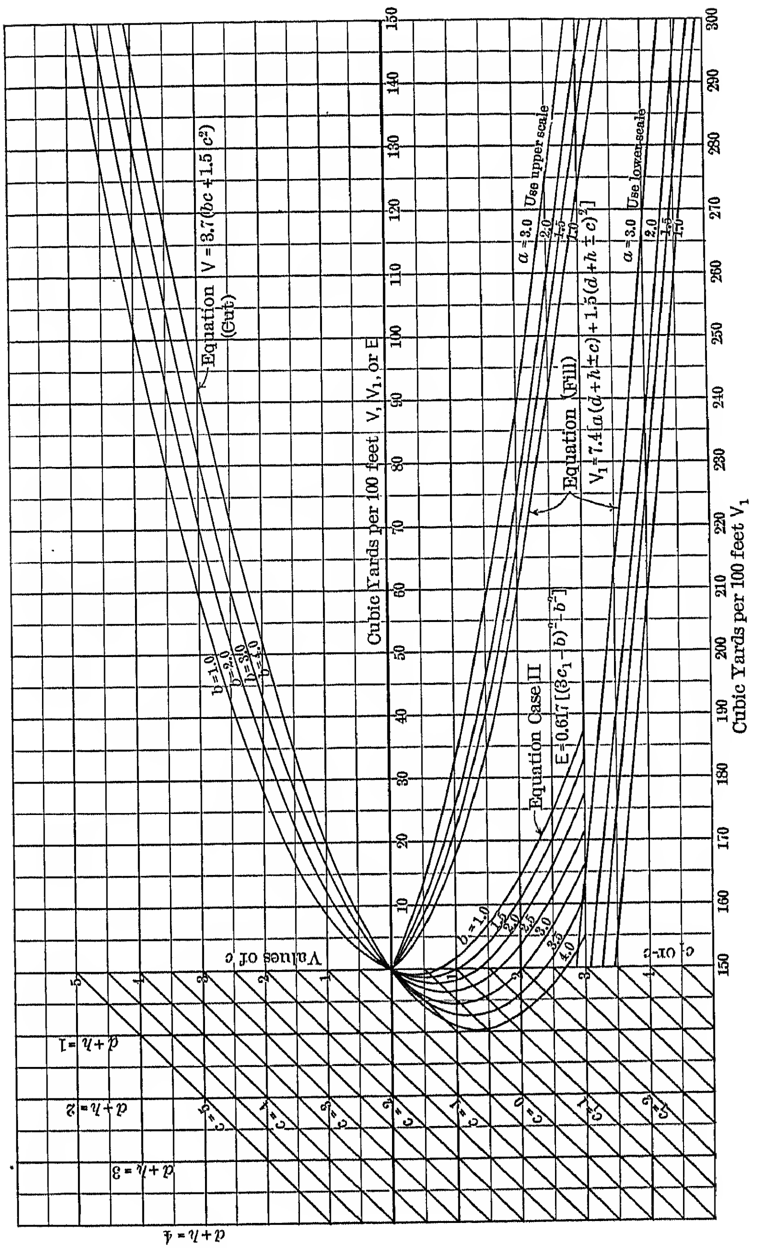
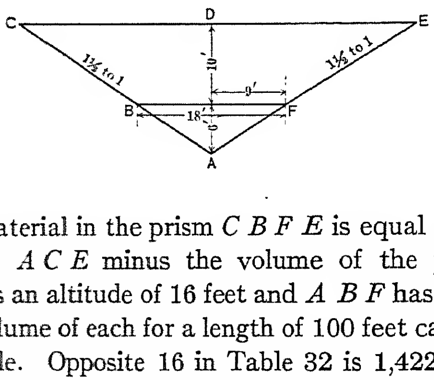


FIG. 39.—Volume of Excavation and Embankment for Small Canals in Level Ground.

The object of using two different scales for the values of V_1 is merely to shorten up the diagram, the lower set of curves for V_1 being a continuation of the four upper curves, and the lower scale a continuation of the upper. Fig. 39 illustrates a simple and rapid means of calculating embankment quantities on level ground. This particular diagram is offered principally as an illustration of the manner of plotting the equations, rather than for practical usefulness, although it may be considered fairly accurate for the range of values of the various factors that it covers. It will be found, however, that for continuous use such a scale is rather hard on the eyes, and larger scales are desirable, which for obvious reasons are not used here.

Tables 31 to 34 give the volume of excavation in cubic yards per 100 feet of length for various center depths and side slopes, assuming the ground to be level transversely. The volume required is the difference between two triangular prisms.

In the figure below is shown the cross-section of a canal that has a bottom width of 18 feet and side slopes of 1½ to 1. The



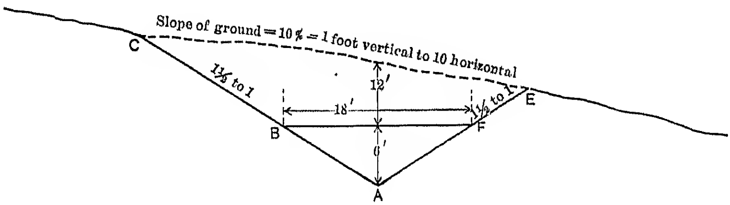
amount of material in the prism $C\,B\,F\,E$ is equal to the volume of the prism $A\,C\,E$ minus the volume of the prism $A\,B\,F$. As $A\,C\,E$ has an altitude of 16 feet and $A\,B\,F$ has an altitude of 6 feet, the volume of each for a length of 100 feet can be obtained from the table. Opposite 16 in Table 32 is 1,422, which is the volume in cubic feet of $A\,C\,E$ per 100 linear feet; opposite 6 is 200, which is the volume of $A\,B\,F$.

As
$$C\,B\,F\,E = A\,C\,E - A\,B\,F$$
$$C\,B\,F\,E = 1{,}422 - 200$$
$$= 1{,}222 \text{ cubic yards}$$

When working up quantities for canal excavation the volume of $A\,B\,F$ need not be subtracted at each station, but need

be subtracted only when a change of canal section or classification of material occurs. When this is done, it is obvious that the volume to be subtracted is the volume of $A\ B\ F$ per 100-foot station multiplied by the number of stations covered. No interpolation is necessary, as the cuts are never measured closer than the nearest 0.1 foot.

Tables 35 to 37 give the volume of excavation in cubic yards per 100 feet of length, where the surface slopes transversely, for various center depths and side slopes. They differ from Tables 31 to 34 only in that the earth surface is sloping ground instead of being level transversely. The surface slope is expressed in per cent, a 10 per cent slope being 10 vertical to 100 horizontal.



In the above figure is shown a section of canal in sloping ground. The depth of center cut to A is 18 feet; entering Table 36, with a depth of 18, we read the volume of $C\ A\ E = 1841$. The volume of $B\ A\ F$ is always read from the tables for level cut; this volume is found in Table 32 to be 200 cubic yards. The volume of the canal prism per 100 feet is, therefore,

$$C\ A\ E - B\ A\ F = 1841 - 200 = 1641 \text{ cubic yards.}$$

When working up quantities for canal excavation, the volume of $B\ A\ F$ need not be subtracted at each station, but need be subtracted only when a change of canal section or classification of material occurs. When this is done, it is obvious that the volume to be subtracted is the volume of $B\ A\ F$ per 100-foot station multiplied by the number of stations covered.

TABLE 31

AMOUNT OF MATERIAL IN CUBIC YARDS PER 100 LINEAR FEET OF LEVEL CUT

Side Slopes 1 to 1

Depth of Center Cut, in Feet	0.	1.	2.	3.	4.	5.	6.	.7	.8	.9
0	0.0	0.0	0.1	0.3	0.6	0.9	1.3	1.8	2.4	3.0
1	3.7	4.5	5.3	6.3	7.3	8.3	9.5	10.7	12.0	13.4
2	15	16	18	20	21	23	25	27	29	31
3	33	36	38	40	43	45	48	51	54	56
4	59	62	65	68	72	75	78	82	85	89
5	93	96	100	104	108	112	116	120	125	129
6	133	138	142	147	152	156	161	166	171	176
7	181	187	192	197	203	208	214	220	225	231
8	237	243	249	255	261	268	274	280	287	293
9	300	307	313	320	327	334	341	349	356	363
10	370	378	385	393	401	408	416	424	432	440
11	448	456	465	473	481	490	498	507	516	524
12	533	542	551	560	569	579	588	597	607	616
13	626	636	645	655	665	675	685	695	705	716
14	726	736	747	757	768	779	789	800	811	822
15	833	844	856	867	878	890	901	913	925	936
16	948	960	972	984	996	1,008	1,021	1,033	1,045	1,058
17	1,070	1,083	1,096	1,108	1,121	1,134	1,147	1,160	1,173	1,187
18	1,200	1,213	1,227	1,240	1,254	1,268	1,281	1,295	1,309	1,323
19	1,337	1,351	1,365	1,380	1,394	1,408	1,423	1,437	1,452	1,467
20	1,481	1,496	1,511	1,526	1,541	1,556	1,572	1,587	1,602	1,618
21	1,633	1,649	1,665	1,680	1,696	1,712	1,728	1,744	1,760	1,776
22	1,793	1,809	1,825	1,842	1,858	1,875	1,892	1,908	1,925	1,942
23	1,959	1,976	1,993	2,011	2,028	2,045	2,063	2,080	2,098	2,116
24	2,133	2,151	2,169	2,187	2,205	2,223	2,241	2,260	2,278	2,296
25	2,315	2,333	2,352	2,371	2,389	2,408	2,427	2,446	2,465	2,484
26	2,504	2,523	2,542	2,562	2,581	2,601	2,621	2,640	2,660	2,680
27	2,700	2,720	2,740	2,760	2,781	2,801	2,821	2,842	2,862	2,883
28	2,904	2,924	2,945	2,966	2,987	3,008	3,029	3,051	3,072	3,093
29	3,115	3,136	3,158	3,180	3,201	3,223	3,245	3,267	3,289	3,331
30	3,333	3,356	3,378	3,400	3,423	3,445	3,468	3,491	3,513	3,536
31	3,559	3,582	3,605	3,628	3,652	3,675	3,698	3,722	3,745	3,769
32	3,793	3,816	3,840	3,864	3,888	3,912	3,936	3,960	3,985	4,009
33	4,033	4,058	4,082	4,107	4,132	4,156	4,181	4,206	4,231	4,256
34	4,281	4,307	4,332	4,357	4,383	4,408	4,434	4,460	4,485	4,511
35	4,537	4,563	4,589	4,615	4,641	4,668	4,694	4,720	4,747	4,773
36	4,800	4,827	4,853	4,880	4,907	4,934	4,961	4,988	5,016	5,043
37	5,070	5,098	5,125	5,153	5,181	5,208	5,236	5,264	5,292	5,320
38	5,348	5,376	5,405	5,433	5,461	5,490	5,518	5,547	5,576	5,604
39	5,633	5,662	5,691	5,720	5,749	5,779	5,808	5,837	5,867	5,896
40	5,926	5,956	5,985	6,015	6,045	6,075	6,105	6,135	6,165	6,196
41	6,226	6,256	6,287	6,317	6,348	6,379	6,409	6,440	6,471	6,502
42	6,533	6,564	6,596	6,627	6,658	6,690	6,721	6,763	6,785	6,816
43	6,848	6,880	6,912	6,944	6,976	7,008	7,041	7,073	7,105	7,138
44	7,170	7,203	7,236	7,268	7,301	7,334	7,367	7,400	7,433	7,467
45	7,500	7,533	7,567	7,600	7,634	7,668	7,701	7,735	7,769	7,803
46	7,837	7,871	7,905	7,940	7,974	8,008	8,043	8,077	8,112	8,147

TABLE 31 (*Concluded*)

AMOUNT OF MATERIAL IN CUBIC YARDS PER 100 LINEAR FEET OF LEVEL CUT

Side Slopes 1 to 1

Depth of Center Cut, in Feet	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
47	8,181	8,216	8,251	8,286	8,321	8,356	8,392	8,427	8,462	8,498
48	8,533	8,569	8,605	8,640	8,676	8,712	8,748	8,784	8,820	8,856
49	8,893	8,929	8,965	9,002	9,038	9,075	9,112	9,148	9,185	9,222
50	9,259	9,296	9,333	9,371	9,408	9,445	9,483	9,520	9,558	9,596
51	9,633	9,671	9,709	9,747	9,785	9,823	9,861	9,900	9,938	9,976
52	10,015	10,053	10,092	10,131	10,169	10,208	10,247	10,286	10,325	10,364
53	10,404	10,443	10,482	10,522	10,561	10,601	10,641	10,680	10,720	10,760
54	10,800	10,840	10,880	10,920	10,961	11 001	11,041	11,082	11,122	11,163
55	11,204	11,244	11,285	11,326	11,367	11,408	11,449	11,491	11,532	11,573
56	11,615	11,656	11,698	11,740	11,781	11,823	11,865	11,907	11,949	11,991
57	12,033	12,076	12,118	12,160	12,203	12,245	12,288	12,331	12,373	12,416
58	12,459	12,502	12,545	12,588	12,632	12,675	12,718	12,762	12,805	12,849
59	12,893	12,936	12,980	13,024	13,068	13,112	13,156	13,200	13,245	13,289
60	13,333	......	......	......	......	......	......	......	......	......

TABLE 32

AMOUNT OF MATERIAL IN CUBIC YARDS PER 100 LINEAR FEET OF LEVEL CUT

Side Slopes $1\frac{1}{2}$ to 1

Depth of Center Cut, in Feet	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	0.0	0.0	0.2	0.5	0.9	1.4	2.0	2.7	3.6	4.5
1	5.6	6.7	8.0	9.4	10.9	12.5	14.2	16.1	18.0	20.1
2	22	24	27	29	32	35	38	41	44	47
3	50	53	57	60	64	68	72	76	80	84
4	89	93	98	103	108	112	118	123	128	133
5	139	144	150	156	162	168	174	180	187	193
6	200	207	214	222	228	235	242	249	257	264
7	272	280	288	296	304	312	321	329	338	347
8	356	364	374	383	392	401	411	420	430	440
9	450	460	470	480	491	501	512	522	533	544
10	556	567	577	589	601	612	624	636	648	660
11	672	684	697	709	722	735	748	760	774	787
12	800	813	827	840	854	868	882	896	910	924
13	939	953	968	983	998	1,012	1,028	1,043	1,058	1,073
14	1,089	1,104	1,120	1,136	1,152	1,168	1,184	1,200	1,217	1,233
15	1,250	1,267	1,284	1,300	1,318	1,335	1,352	1,369	1,387	1,404

TABLE 32 (*Concluded*)

AMOUNT OF MATERIAL IN CUBIC YARDS PER 100 LINEAR FEET OF LEVEL CUT

Side Slopes $1\frac{1}{2}$ to 1

Depth of Center Cut, in Feet	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
16	1,422	1,440	1,458	1,476	1,494	1,512	1,531	1,549	1,568	1,587
17	1,606	1,624	1,644	1,663	1,682	1,701	1,721	1,740	1,760	1,780
18	1,800	1,820	1,840	1,860	1,881	1,901	1,922	1,943	1,964	1,984
19	2,006	2,027	2,048	2,069	2,091	2,112	2,134	2,156	2,178	2,200
20	2,222	2,244	2,267	2,289	2,311	2,335	2,358	2,380	2,404	2,427
21	2,450	2,473	2,497	2,520	2,544	2,568	2,592	2,616	2,640	2,664
22	2,689	2,713	2,738	2,763	2,788	2,812	2,838	2,863	2,888	2,913
23	2,939	2,964	2,990	3,016	3,042	3,068	3,094	3,120	3,147	3,173
24	3,200	3,227	3,254	3,280	3,308	3,335	3,362	3,389	3,417	3,444
25	3,472	3,500	3,528	3,556	3,584	3,612	3,641	3,669	3,698	3,727
26	3,756	3,784	3,814	3,843	3,872	3,901	3,931	3,960	3,990	4,020
27	4,050	4,080	4,110	4,140	4,171	4,201	4,232	4,263	4,294	4,324
28	4,356	4,387	4,418	4,449	4,481	4,512	4,544	4,576	4,608	4,640
29	4,672	4,704	4,737	4,769	4,802	4,835	4,868	4,900	4,934	4,967
30	5,000	5,033	5,067	5,100	5,134	5,168	5,202	5,236	5,270	5,304
31	5,339	5,373	5,408	5,443	5,478	5,512	5,548	5,583	5,618	5,653
32	5,689	5,724	5,760	5,796	5,832	5,868	5,904	5,940	5,977	6.013
33	6,050	6,087	6,124	6 160	6,198	6,235	6,272	6,309	6,347	6,384
34	6,422	6,460	6,498	6,536	6,574	6,612	6,651	6,689	6,728	6,767
35	6,806	6,844	6,884	6,923	6,962	7,001	7,041	7,080	7,120	7,160
36	7,200	7,240	7,280	7,320	7,361	7,401	7,442	7,483	7,524	7,564
37	7,606	7,647	7,688	7,729	7,771	7,812	7,854	7,896	7,938	7,980
38	8,022	8,064	8,107	8,149	8,192	8,235	8,278	8,320	8,364	8,407
39	8,450	8,493	8,537	8,580	8,624	8,668	8,712	8,756	8,800	8,844
40	8,889	8,933	8,978	9,023	9,068	9,112	9,158	9,203	9,248	9,293
41	9,339	9,384	9,430	9,476	9,522	9,568	9,614	9,660	9,707	9,753
42	9,800	9,847	9,894	9,940	9,988	10,035	10,082	10,129	10,177	10,224
43	10,272	10,320	10,368	10,416	10,464	10,512	10,561	10,609	10,658	10,707
44	10,756	10,804	10,854	10,903	10,952	11,001	11,051	11,100	11,150	11,200
45	11,250	11,300	11,350	11,400	11,451	11,501	11,552	11,603	11,654	11,704
46	11,756	11,807	11,858	11,909	11,961	12,012	12,064	12,116	12,168	12,220
47	12,272	12,324	12,377	12,429	12,482	12,535	12,588	12,640	12,694	12,747
48	12,800	12,853	12,907	12,960	13,014	13,068	13,122	13,176	13,230	13,284
49	13,339	13,393	13,448	13,503	13,558	13,612	13,668	13,723	13,778	13,833
50	13,889	13,944	14,000	14,056	14,112	14,168	14,224	14,280	14,337	14,392
51	14,450	14,507	14,564	14,620	14,678	14,735	14,792	14,849	14,987	14,964
52	15,022	15,080	15,138	15,196	15,254	15,312	15,371	15,430	15,489	15,548
53	15,606	15,664	15,724	15,783	15,842	15,901	15,961	16,020	16,080	16,140
54	16,200	16,260	16,320	16,380	16,441	16,501	16,562	16,623	16,684	16,744
55	16,806	16,867	16,928	16,989	17,051	17,112	17,174	17,236	17,298	17,360
56	17,422	17,484	17,547	17,609	17,672	17,735	17,798	17,860	17,924	17,987
57	18,050	18,113	18,177	18,240	18,304	18,368	18,432	18,496	18,560	18,624
58	18,689	18,753	18,818	18,883	18,948	19,012	19,078	19,143	19,208	19,273
59	19,339	19,404	19,470	19,536	19,602	19,668	19,734	19,800	19,867	19,933
60	20,000	......	......	......	......	......	......	......	......	......

TABLE 33

AMOUNT OF MATERIAL IN CUBIC YARDS PER 100 LINEAR FEET OF LEVEL CUT

Side Slopes 2 to 1

Depth of Center Cut, in Feet	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	0.0	0.1	0.3	0.7	1.2	1.9	2.7	3.6	4.7	6.0
1	7.4	9.0	10.7	12.5	14.5	16.7	19.0	21.4	24.0	26.7
2	30	33	36	39	43	46	50	54	58	62
3	67	71	76	81	86	91	96	101	107	113
4	119	125	131	137	143	150	157	164	171	178
5	185	193	200	208	216	224	232	241	249	258
6	267	276	285	294	303	313	323	333	343	353
7	363	373	384	395	406	417	428	439	451	462
8	474	486	498	510	523	535	548	561	574	587
9	600	613	627	641	655	669	683	697	711	726
10	741	756	771	786	801	817	832	848	864	880
11	896	913	929	946	963	980	997	1,014	1,031	1,049
12	1,067	1,084	1,103	1,121	1,139	1,157	1,176	1,195	1,214	1,233
13	1,252	1,271	1,291	1,310	1,330	1,350	1,370	1,390	1,411	1,431
14	1,452	1,473	1,494	1,515	1,536	1,557	1,579	1,601	1,623	1,645
15	1,667	1,689	1,711	1,734	1,757	1,780	1,803	1,826	1,849	1,873
16	1,896	1,920	1,944	1,968	1,992	2,017	2,041	2,066	2,091	2,116
17	2,141	2,166	2,191	2,217	2,243	2,269	2,295	2,321	2,347	2,373
18	2,400	2,427	2,454	2,481	2,508	2,535	2,563	2,590	2,618	2,646
19	2,674	2,702	2,731	2,759	2,788	2,817	2,846	2,875	2,904	2,938
20	2,963	2,993	3,023	3,053	3,083	3,113	3,143	3,174	3,205	3,236
21	3,267	3,298	3,329	3,361	3,392	3,424	3,456	3,488	5,520	3,553
22	3,585	3,618	3,651	3,684	3,717	3,750	3,783	3,817	3,851	3,885
23	3,919	3,953	3,987	4,021	4,056	4,091	4,126	4,161	4,196	4,231
24	4,267	4,302	4,338	4,374	4,410	4,446	4,483	4,519	4,556	4,593
25	4,630	4,667	4,704	4,741	4,779	4,817	4,855	4,893	4,931	4,969
26	5,007	5,046	5,085	5,124	5,163	5,202	5,241	5,281	5,320	5,360
27	5,400	5,440	5,480	5,521	5,561	5,602	5,643	5,684	5,725	5,766
28	5,807	5,849	5,891	5,933	5,975	6,017	6,059	6,101	6,144	6,187
29	6,230	6,273	6,316	6,359	6,403	6,446	6,490	6,534	6,578	6,622
30	6,667	6,711	6,756	6,801	6,846	6,891	6,936	6,981	7,027	7,073
31	7,119	7,165	7,211	7,257	7,303	7,350	7,397	7,444	7,491	7,538
32	7,585	7,633	7,680	7,728	7,776	7,824	7,872	7,921	7,969	8,018
33	8,067	8,116	8,165	8,214	8,263	8,313	8,363	8,413	8,463	8,513
34	8,563	8,613	8,664	8,715	8,766	8,817	8,868	8,919	8,971	9,022
35	9,074	9,126	9,178	9,230	9,283	9,335	9,388	9,441	9,494	9,547
36	9,600	9,653	9,707	9,761	9,815	9,869	9,923	9,977	10,031	10,086
37	10,141	10,196	10,251	10,306	10,361	10,417	10,472	10,528	10,584	10,640
38	10,696	10,753	10,809	10,866	10,923	10,980	11,037	11,094	11,151	11,209
39	11,267	11,325	11,383	11,441	11,499	11,557	11,616	11,675	11,734	11,793
40	11,852	11,911	11,971	12,030	12,090	12,150	12,210	12,270	12,331	12,391
41	12,452	12,513	12,574	12,635	12,696	12,757	12,810	12,881	12,943	13,005
42	13,067	13,129	13,191	13,254	13,317	13,380	13,443	13,506	13,569	13,633
43	13,696	13,760	13,824	13,888	13,952	14,017	14,081	14,146	14,211	14,276
44	14,341	14,406	14,471	14,537	14,603	14,669	14,735	14,801	14,867	14,933

TABLE 33 (*Concluded*)

AMOUNT OF MATERIAL IN CUBIC YARDS PER 100 LINEAR FEET OF LEVEL CUT

Side Slopes 2 to 1

Depth of Center Cut, in Feet	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
45	15,000	15,067	15,134	15,201	15,268	15,335	15,403	15,470	15,538	15,606
46	15,674	15,742	15,811	15,879	15,948	16,017	16,086	16,155	16,224	16,293
47	16,363	16,433	16,503	16,573	16,643	16,713	16,783	16,854	16,925	16,996
48	17,067	17,138	17,209	17,281	17,352	17,424	17,496	17,568	17,640	17,713
49	17,785	17,858	17,931	18,004	18,077	18,150	18,223	18,297	18,371	18,445
50	18,519	18,593	18,667	18,741	18,816	18,891	18,966	19,041	19,116	19,191
51	19,267	19,342	19,418	19,494	19,570	19,646	19,723	19,799	19,876	19,953
52	20,030	20,107	20,184	20,261	20,339	20,417	20,495	20,573	20,651	20,729
53	20,807	20,886	20,965	21,044	21,123	21,202	21,281	21,361	21,440	21,520
54	21,600	21,680	21,760	21,841	21,921	22,002	22,083	22,164	22,245	22,326
55	22,407	22,489	22,571	22,653	22,735	22,817	22,899	22,981	23,064	23,147
56	23,230	23,313	23,396	23,479	23,563	23,646	23,730	23,814	23,898	23,982
57	24,067	24,151	24,236	24,321	24,406	24,491	24,576	24,661	24,747	24,833
58	24,919	25,005	25,091	25,177	25,263	25,350	25,447	25,524	25,611	25,698
59	25,785	25,873	25,960	26,048	26,136	26,224	26,312	26,401	26,489	26,578
60	26,667	......	......	......	......	......	......	......	......	......

TABLE 34

AMOUNT OF MATERIAL IN CUBIC YARDS PER 100 LINEAR FEET OF LEVEL CUT

Side Slopes 3 to 1

Depth of Center Cut, in Feet	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	0.0	0.1	0.4	1.0	1.8	2.8	4.0	5.4	7.1	9.0
1	11 1	13.4	16.0	18.8	21.8	25.0	28.4	32.2	36.1	40.1
2	44	49	54	59	64	69	75	81	87	93
3	100	106	114	121	128	136	144	152	160	168
4	178	187	196	205	215	225	235	245	256	267
5	278	289	300	312	324	336	348	361	373	387
6	400	413	427	441	445	469	484	499	514	529
7	544	560	576	592	608	625	642	659	676	693
8	711	729	747	765	784	803	822	841	860	880
9	900	920	940	961	982	1,003	1,024	1,045	1,067	1,089
10	1,111	1,133	1,156	1,179	1,202	1,225	1,248	1,272	1,296	1,320
11	1,344	1,369	1,394	1,419	1,444	1,469	1,495	1,521	1,547	1,573
12	1,600	1,627	1,654	1,681	1,708	1,736	1,764	1,792	1,820	1,849
13	1,878	1,907	1,936	1,965	1,995	2,025	2,055	2,085	2,116	2,147
14	2,178	2,209	2,240	2,272	2,304	2,336	2,368	2,401	2,434	2,467

TABLE 34 (*Concluded*)

MATERIAL IN CUBIC YARDS PER 100 LINEAR FEET OF LEVEL CUT

Side Slopes 3 to 1

.1	.2	.3	.4	.5	.6	.7	.8	.9
2,533	2,567	2,601	2,635	2,669	2,704	2,739	2,774	2,809
2,880	2,916	2,952	2,988	3,025	3,062	3,099	3,136	3,173
3,249	3,287	3,325	3,364	3,403	3,442	3,481	3,520	3,560
3,640	3,680	3,721	3,762	3,803	3,844	3,885	3,927	3,969
4,053	4,096	4,139	4,182	4,225	4,268	4,312	4,356	4,400
4,489	4,534	4,579	4,624	4,669	4,715	4,761	4,807	4,853
4,947	4,994	5,041	5,088	5,137	5,184	5,232	5,280	5,329
5,427	5,476	5,525	5,575	5,625	5,675	5,725	5,776	5,827
5,929	5,980	6,032	6,084	6,136	6,188	6,240	6,294	6,346
6,453	6,507	6,561	6,615	6,669	6,724	6,779	6,834	6,889
7,000	7,056	7,112	7,168	7,225	7,282	7,339	7,396	7,453
7,569	7,627	7,685	7,744	7,803	7,862	7,921	7,980	8,040
8,160	8,220	8,281	8,342	8,403	8,464	8,525	8,587	8,649
8,773	8,836	8,899	8,962	9,025	9,088	9,152	9,216	9,280
9,409	9,474	9,539	9,604	9,669	9,735	9,801	9,867	9,993
10,067	10,134	10,201	10,268	10,336	10,404	10,472	10,540	10,609
10,747	10,816	10,885	10,955	11,025	11,095	11,165	11,236	11,307
11,449	11,520	11,592	11,664	11,736	11,808	11,881	11,954	12,027
12,173	12,247	12,321	12,395	12,469	12,544	12,619	12,694	12,769
12,920	12,996	13,072	13,148	13,225	13,302	13,379	13,456	13,533
13,689	13,767	13,845	13,924	14,003	14,082	14,161	14,240	14,320
14,480	14,560	14,641	14,722	14,803	14,884	14,965	15,047	15,129
15,293	15,376	15,459	15,542	15,625	15,708	15,792	15,876	15,960
16,129	16,214	16,299	16,384	16,469	16,555	16,641	16,727	16,813
16,987	17,074	17,161	17,248	17,336	17,424	17,512	17,600	17,689
17,867	17,956	18,045	18,135	18,225	18,315	18,405	18,496	18,587
18,769	18,860	18,952	19,044	19,136	19,228	19,321	19,414	19,507
19,693	19,787	19,881	19,975	20,069	20,164	20,259	20,354	20,449
20,640	20,736	20,832	20,928	21,025	21,122	21,219	21,316	21,413
21,609	21,707	21,805	21,904	22,003	22,102	22,201	22,300	22,400
22,600	22,700	22,801	22,902	23,003	23,104	23,205	23,307	23,409
23,613	23,716	23,819	23,922	24,025	24,128	24,232	24,336	24,440
24,649	24,754	24,859	24,964	25,069	25,175	25,281	25,387	25,493
25,707	25,814	25,921	26,029	26,136	26,244	26,352	26,460	26,569
26,787	26,896	27,005	27,115	27,225	27,335	27,445	27,556	27,667
27,889	28,000	28,112	28,224	28,336	28,448	28,561	28,674	28,787
29,013	29,127	29,241	29,355	29,469	29,584	29,699	29,814	29,929
30,160	30,276	30,392	30,508	30,625	30,742	30,859	30,976	31,093
31,329	31,447	31,565	31,684	31,803	31,922	32,041	32,160	32,280
32,520	32,640	32,761	32,882	33,003	33,124	33,245	33,367	33,489
33,733	33,856	33,979	34,102	34,225	34,348	34,472	34,596	34,720
34,969	35,094	35,219	35,344	35,459	35,595	35,721	35,847	35,973
36,227	35,354	36,481	36,608	36,736	36,864	36,992	37,120	37,249
37,507	37,636	37,765	37,895	38,025	38,155	38,285	38,416	38,547
38,809	38,940	39,072	39,204	39,336	39,468	39,601	39,734	39,867
......	......	......	......	......	......	......	......	......

TABLE 35

Amount of Material in Cubic Yards per 100 Linear Feet of Cut on Sloping Ground

Side Slopes 1 to 1

Depth of Center Cut, in Feet	Surface Slope of Ground in per Cent										
	10	15	20	25	30	35	40	45	50	55	60
1.0	4	4	4	4	4	4	5	5	5	6	6
1.5	8	8	9	9	9	9	10	10	11	12	13
2.0	15	15	16	16	16	17	18	19	20	21	23
2.5	23	24	24	25	25	27	27	29	31	33	36
3.0	33	33	34	35	36	38	39	42	44	47	52
3.5	46	46	47	48	49	51	54	57	60	65	70
4.0	59	60	61	63	65	67	70	74	79	85	92
4.5	76	77	78	80	83	85	89	94	100	107	117
5.0	94	95	97	99	102	106	111	117	124	133	145
5.5	113	114	117	120	123	128	133	141	149	161	175
6.0	134	136	139	142	146	152	158	167	177	191	208
6.5	157	160	163	166	172	178	186	196	208	224	244
7.0	183	185	189	193	199	206	215	227	242	260	283
7.5	210	212	217	222	229	237	248	261	278	299	325
8.0	239	242	247	253	261	270	282	297	316	340	370
8.5	270	274	279	286	295	305	319	336	357	384	418
9.0	303	307	312	320	330	342	357	376	400	430	468
9.5	338	342	348	356	367	381	398	419	446	479	522
10.0	374	378	385	395	406	422	441	464	494	531	578
10.5	412	417	425	436	448	465	486	512	545	585	637
11.0	453	458	467	478	492	510	533	562	598	642	700
11.5	495	501	510	523	538	558	583	615	653	702	765
12.0	539	545	555	569	586	607	634	669	711	764	833
12.5	585	592	603	618	637	659	689	726	772	830	904
13.0	632	640	652	668	689	713	745	785	835	897	978
13.5	681	691	703	720	743	769	803	847	900	967	1,054
14.0	733	743	756	774	799	827	864	911	968	1,040	1,134
14.5	787	797	811	831	857	887	927	977	1,039	1,116	1,216
15.0	841	852	868	888	916	949	994	1,045	1,111	1,194	1,301
15.5	898	910	927	949	978	1,014	1,059	1,116	1,187	1,276	1,390
16.0	957	970	987	1,011	1,042	1,080	1,128	1,189	1,264	1,359	1,480
16.5	1,018	1,031	1,050	1,075	1,108	1,148	1,199	1,265	1,344	1,445	1,573
17.0	1,080	1,095	1,115	1,141	1,176	1,219	1,273	1,343	1,427	1,534	1,669
17.5	1,145	1,160	1,182	1,209	1,246	1,292	1,349	1,423	1,512	1,626	1,770
18.0	1,212	1,227	1,250	1,280	1,319	1,368	1,428	1,506	1,600	1,720	1,874
18.5	1,281	1,297	1,321	1,353	1,394	1,445	1,509	1,591	1,691	1,817	1,980
19.0	1,351	1,368	1,393	1,426	1,470	1,523	1,591	1,678	1,783	1,916	2,088
19.5	1,422	1,440	1,467	1,502	1,548	1,604	1,676	1,767	1,878	2,018	2,199
20.0	1,496	1,515	1,542	1,580	1,628	1,687	1,763	1,859	1,975	2,123	2,313
20.5	1,572	1,592	1,620	1,660	1,710	1,773	1,852	1,953	2,075	2,230	2,430
21.0	1,649	1,670	1,701	1,742	1,795	1,861	1,943	2,049	2,178	2,340	2,550
21.5	1,729	1,751	1,783	1,826	1,882	1,951	2,037	2,148	2,283	2,453	2,673
22.0	1,811	1,834	1,868	1,913	1,971	2,043	2,134	2,250	2,391	2,569	2,800
22.5	1,894	1,918	1,953	2,001	2,061	2,136	2,231	2,353	2,501	2,687	2,928
23.0	1,979	2,004	2,041	2,090	2,153	2,232	2,331	2,458	2,613	2,808	3,059

TABLE 35 (*Concluded*)

AMOUNT OF MATERIAL IN CUBIC YARDS PER 100 LINEAR FEET OF CUT ON SLOPING GROUND

Side Slopes 1 to 1

Depth of Center Cut, in Feet	Surface Slope of Ground in per Cent										
	10	15	20	25	30	35	40	45	50	55	60
23.5	2,065	2,091	2,130	2,181	2,247	2,330	2,434	2,566	2,728	2,931	3,194
24.0	2,154	2,181	2,221	2,275	2,344	2,430	2,539	2,677	2,845	3,057	3,331
24.5	2,245	2,274	2,315	2,371	2,443	2,533	2,646	2,790	2,965	3,186	3,472
25.0	2,338	2,368	2,411	2,469	2,545	2,637	2,755	2,905	3,088	3,318	3,615
25.5	2,432	2,463	2,508	2,568	2,647	2,743	2,866	3,022	3,212	3,451	3,761
26.0	2,529	2,561	2,608	2,670	2,752	2,852	2,980	3,142	3,340	3,588	3,910
26.5	2,627	2,661	2,709	2,774	2,859	2,963	3,095	3,264	3,469	3,727	4,062
27.0	2,727	2,762	2,813	2,880	2,968	3,076	3,212	3,388	3,601	3,869	4,217
27.5	2,829	2,865	2,918	2,988	3,079	3,191	3,332	3,515	3,736	4,014	4,374
28.0	2,932	2,970	3,024	3,097	3,191	3,308	3,454	3,643	3,872	4,161	4,534
28.5	3,038	3,077	3,133	3,208	3,306	3,427	3,579	3,775	4,012	4,311	4,698
29.0	3,146	3,187	3,245	3,322	3,423	3,548	3,706	3,909	4,154	4,464	4,864
29.5	3,255	3,297	3,357	3,438	3,542	3,671	3,835	4,045	4,298	4,619	5,033
30.0	3,367	3,409	3,471	3,555	3,663	3,797	3,967	4.183	4,445	4,777	5,205
30.5	3,480	3,524	3,588	3,675	3,786	3,924	4,100	4,323	4,595	4,937	5,380
31.0	3,595	3,641	3,707	3,796	3,911	4,054	4,236	4,466	4,747	5,100	5,558
31.5	3,712	3,759	3,828	3,920	4,039	4,187	4,374	4,612	4,901	5,266	5,739
32.0	3,831	3,880	3,951	4,046	4,169	4,322	4,514	4,760	5,058	5,435	5,923
32.5	3,952	4,002	4,075	4,173	4,300	4,457	4,656	4,909	5,217	5,606	6,109
33.0	4,074	4,126	4,201	4,302	4,433	4,595	4,800	5,061	5,379	5,780	6,298
33.5	4,198	4,252	4,329	4,433	4,568	4,735	4,946	5,215	5,543	5,956	6,491
34.0	4,324	4,379	4,459	4,566	4,705	4,877	5,095	5,372	5,710	6,135	6,686
34.5	4,452	4,509	4,592	4,702	4,845	5,022	5,246	5,531	5,879	6,317	6,884
35.0	4,583	4,641	4,726	4,839	4,987	5,169	5,399	5,693	6,051	6,502	7,085
35.5	4,714	4,774	4,861	4,978	5,130	5,317	5,555	5,856	6,225	6,689	7,288
36.0	4,848	4,910	5,000	5,120	5,276	5,469	5,712	6,023	6,402	6,879	7,496
36.5	4,984	5,048	5,140	5,263	5,423	5,621	5,872	6,191	6,581	7,071	7,705
37.0	5,122	5,187	5,282	5,408	5,573	5,776	6,034	6,362	6,762	7,266	7,918
37.5	5,261	5,328	5,426	5,555	5,725	5,933	6,198	6,535	6,946	7,464	8,132
38.0	5,402	5,471	5,571	5,705	5,879	6,093	6,365	6,711	7,133	7,665	8,353
38.5	5,545	5,615	5,718	5,855	6,033	6,254	6,532	6,888	7,321	7,867	8,572
39.0	5,690	5,763	5,868	6,008	6,191	6,418	6,703	7,069	7,513	8,073	8,797
39.5	5,837	5,912	6,020	6,164	6,351	6,584	6,877	7,252	7,707	8,282	9,024
40.0	5,986	6,062	6,173	6,321	6,513	6,752	7,052	7,436	7,903	8,493	9,254
40.5	6,137	6,215	6,328	6,480	6,677	6,921	7,230	7,623	8,102	8,706	9,487
41.0	6,289	6,369	6,485	6,641	6,843	7,093	7,410	7,813	8,304	8,922	9,722
41.5	6,442	6,524	6,644	6,803	7,011	7,266	7,591	8,004	8,507	9,140	9,961
42.0	6,599	6,683	6,806	6,969	7,181	7,443	7,775	8,198	8,713	9,362	10,203
42.5	6,758	6,844	6,969	7,136	7,353	7,622	7,962	8,395	8,922	9,587	10,447
43.0	6,917	7,006	7,134	7,305	7,527	7,802	8,150	8,593	9,133	9,814	10,694
43.5	7,079	7,170	7,300	7,476	7,703	7,984	8,341	8,794	9,347	10,043	10,944
44.0	7,243	7,335	7,469	7,648	7,880	8,169	8,533	8,997	9,563	10,175	11,197

TABLE 36

Amount of Material in Cubic Yards per 100 Linear Feet of Cut on Sloping Ground

Side Slopes $1\frac{1}{2}$ to 1

Depth of Center Cut, in Feet	Surface Slope of Ground in per Cent										
	10	15	20	25	30	35	40	45	50	55	60
0.5	1	1	1	1	1	1	1	2	2	2	6
1.0	6	6	7	7	7	8	9	11	13	18	29
1.5	12	13	13	14	15	17	19	22	28	39	65
2.0	23	23	24	26	28	38	34	41	51	70	117
2.5	36	37	38	41	44	48	55	64	80	109	183
3.0	51	53	55	58	63	69	78	92	114	157	263
3.5	70	72	75	79	85	94	106	125	155	213	357
4.0	91	94	98	104	112	123	139	163	203	278	467
4.5	113	118	124	132	141	155	176	206	257	352	590
5.0	142	146	153	162	174	192	217	255	318	435	730
5.5	172	177	185	195	211	232	262	309	384	526	882
6.0	205	211	220	233	251	276	312	368	457	624	1,051
6.5	240	248	258	273	295	324	367	431	537	735	1,233
7.0	278	287	299	317	341	375	425	500	622	852	1,430
7.5	319	329	343	363	391	430	488	574	714	978	1,641
8.0	364	375	391	414	446	491	556	654	813	1,113	1,870
8.5	411	423	441	467	503	555	627	738	918	1,257	2,107
9.0	460	474	495	524	564	622	703	827	1,029	1,409	2,364
9.5	513	528	552	583	628	691	783	922	1,146	1,569	2,633
10.0	569	585	611	647	697	765	868	1,021	1,271	1,740	2,919
10.5	627	645	673	712	768	844	956	1,125	1,401	1,918	3,217
11.0	687	708	739	781	843	927	1,049	1,235	1,537	2,104	3,531
11.5	752	774	808	855	922	1,013	1,149	1,350	1,680	2,301	3,860
12.0	819	843	879	931	1,003	1,103	1,250	1,470	1,829	2,504	4,203
12.5	888	914	954	1,010	1,089	1,197	1,356	1,595	1,985	2,717	4,560
13.0	961	989	1,032	1,093	1,178	1,295	1,467	1,725	2,147	2,939	4,933
13.5	1,036	1,066	1,112	1,178	1,269	1,396	1,581	1,860	2,316	3,170	5,318
14.0	1,114	1,147	1,196	1,267	1,365	1,502	1,701	2,001	2,489	3,410	5,721
14.5	1,195	1,230	1,284	1,359	1,465	1,612	1,825	2,146	2,669	3,657	6,136
15.0	1,279	1,316	1,374	1,454	1,568	1,724	1,952	2,297	2,857	3,914	6,567
15.5	1,366	1,406	1,467	1,553	1,674	1,841	2,085	2,453	3,051	4,179	7,012
16.0	1,455	1,498	1,563	1,654	1,784	1,961	2,221	3,613	3,250	4,453	7,472
16.5	1,547	1,593	1,662	1,759	1,897	2,085	2,362	2,779	3,456	4,735	7,945
17.0	1,643	1,691	1,765	1,868	2,014	2,214	2,507	2,951	3,670	5,027	8,435
17.5	1,741	1,792	1,870	1,979	2,134	2,346	2,656	3,126	3,889	5,326	8,937
18.0	1,841	1,896	1,979	2,094	2,258	2,482	2,809	3,308	4,114	5,636	9,456
18.5	1,945	2,002	2,090	2,212	2,385	2,622	2,967	3,494	4,346	5,953	9,988
19.0	2,051	2,111	2,205	2,334	2,516	2,766	3,130	3,686	4,585	6,279	10,535
19.5	2,160	2,225	2,322	2,458	2,650	2,913	3,299	3,881	4,828	6,614	11,097
20.0	2,272	2,341	2,442	2,586	2,787	3,064	3,472	4,083	5,079	6,957	11,673
20.5	2,387	2,460	2,566	2,717	2,929	3,220	3,648	4,289	5,337	7,310	12,265
21.0	2,506	2,581	2,692	2,851	3,073	3,379	3,828	4,502	5,600	7,670	12,871
21.5	2,627	2,705	2,822	2,988	3,221	3,541	4,013	4,719	5,870	8,040	13,491
22.0	2,751	2,832	2,955	3,129	3,373	3,708	4,201	4,941	6,147	8,417	14,127
22.5	2,877	2,962	3,090	3,272	3,527	3,878	4,394	5,168	6,429	8,804	14,775

TABLE 36 (*Concluded*)

AMOUNT OF MATERIAL IN CUBIC YARDS PER 100 LINEAR FEET OF CUT ON SLOPING GROUND

Side Slopes $1\frac{1}{2}$ to 1

Depth of Center Cut, in Feet	Surface Slope of Ground in per Cent										
	10	15	20	25	30	35	40	45	50	55	60
23.0	3,007	3,096	3,229	3,420	3,686	4,053	4,592	5,400	6,718	9,201	15,440
23.5	3,139	3,232	3,372	3,570	3,848	4,231	4,794	5,638	7,013	9,606	16,118
24.0	3,274	3,371	3,517	3,724	4,014	4,413	5,000	5,881	7,314	10,019	16,812
24.5	3,412	3,513	3,665	3,881	4,183	4,599	5,211	6,129	7,622	10,441	17,519
25.0	3,552	3,657	3,816	4,040	4,355	4,788	5,425	6,382	7,936	10,871	18 242
25.5	3,695	3,804	3,970	4,203	4,531	4,981	5,644	6,639	8,256	11,310	18,978
26.0	3,842	3,954	4,128	4,370	4,711	5,178	5,868	6,902	8,584	11,758	19,731
26.5	3,991	4,109	4,288	4,539	4,892	5,380	6,095	7,169	8,917	12 215	20,497
27.0	4,144	4,266	4,451	4,712	5,080	5,585	6,328	7,443	9,257	12,680	21,277
27.5	4,298	4,425	4,617	4,888	5,270	5,793	6,564	7,721	9,603	13,153	22,072
28.0	4,456	4,588	4,786	5,068	5,464	6.006	6,805	8,005	9,956	13,637	22,881
28.5	4,616	4,753	4,958	5,250	5,661	6,223	7,050	8,292	10,314	14,128	23,706
29.0	4,779	4,921	5,134	5,436	5,860	6,443	7,300	8,586	10,680	14,627	24,546
29.5	4,946	5,093	5,313	5,626	6,064	6,667	7,555	8,885	11,052	15,136	25,399
30.0	5,115	5,267	5,495	5,818	6,272	6,895	7,813	9,189	11,429	15,654	26,268
30.5	5,287	5,444	5,680	6,014	6,482	7,127	8,076	9,497	11,813	16,181	27,150
31.0	5,462	5,624	5,868	6,213	6,697	7,363	8,342	9,811	12,203	16,715	28,047
31.5	5,639	5,806	6,058	6,414	6,914	7,602	8,613	10,130	12,600	17,259	28,958
32.0	5,820	5,992	6,252	6,619	7,136	7,845	8,889	10,455	13,004	17,811	29,885
32.5	6,003	6,180	6,449	6,828	7,360	8,092	9,169	10,784	13,413	18,372	30,826
33.0	6,189	6,372	6,649	7,040	7,589	8,343	9,453	11,119	13,829	18,941	31,782
33.5	6,378	6,567	6,852	7,255	7,821	8,598	9,742	11,458	14,251	19,520	32,753
34.0	6,570	6,764	7,057	7,472	8,055	8,856	10,034	11,802	14,680	20,105	33,738
34.5	6,764	6,964	7,266	7,693	8,294	9,118	10,331	12,151	15,115	20,701	34,738
35.0	6,962	7,168	7,479	7,919	8,537	9,385	10,634	12,506	15,557	21,307	35,754
35.5	7,162	7,374	7,694	8,147	8,783	9,655	10,940	12,865	16,004	21,921	36,782
36.0	7,366	7,584	7,913	8,378	9,032	9,929	11,250	13,230	16,458	22,542	37,826
36.5	7,572	7,796	8,134	8,612	9,284	10,206	11,565	13,601	16,919	23,172	38,884
37.0	7,780	8,011	8,359	8,850	9,540	10,482	11,883	13,977	17,386	23,812	39,958
37.5	7,991	8,229	8,585	9,090	9,799	10,773	12,206	14,356	17,857	24,461	41,045
38.0	8,206	8,450	8,816	9,334	10,062	11,062	12,535	14,742	18,337	25,116	42,148
38.5	8,424	8,674	9,050	9,582	10,329	11,356	12,867	15,133	18,823	25,781	43,266
39.0	8,644	8,900	9,286	9,832	10,599	11,652	13,203	15,528	19,315	26,455	44,398
39.5	8,867	9,130	9,526	10,086	10,873	11,952	13,544	15,929	19,814	27,137	45,545
40.0	9,093	9,363	9,769	10,343	11,150	12,258	13,889	16,335	20,319	27,829	46,699
40.5	9,322	9,598	10,014	10,603	11,430	12,567	14,236	16,745	20,829	28,529	47,873
41.0	9,554	9,836	10,263	10,867	11,714	12,879	14,590	17,163	21,346	29,238	49,062
41.5	9,788	10,078	10,515	11,133	12,002	13,195	14,950	17,584	21,870	29,955	50,265
42.0	10,025	10,322	10,770	11,403	12,293	13,515	15,313	18,010	22,401	30,682	51,483
42.5	10,266	10,569	11,028	11,677	12,587	13,838	15,679	18,441	22,937	31,417	52,716
43.0	10,509	10,819	11,289	11,953	12,885	14,166	16,049	18,877	23,480	32,160	53,963
43.5	10,754	11,072	11,553	12,233	13,186	14,497	16,425	19,319	24,029	32,912	55,225
44.0	11,003	11,329	11,821	12,516	13,492	14,833	16,805	19,766	24,586	33,674	56,506

TABLE 37

Amount of Material in Cubic Yards per 100 Linear Feet of Cut on Sloping Ground

Side Slopes 2 to 1

Depth of Center Cut, in Feet	Surface Slope of Ground in per Cent							
	10	15	20	25	30	35	40	45
0.5	2	2	2	3	3	4	5	10
1.0	7	8	8	9	11	14	20	38
1.5	18	19	20	23	26	33	47	87
2.0	31	33	36	40	47	58	83	156
2.5	48	51	55	61	72	90	128	244
3.0	70	74	80	89	104	131	186	352
3.5	95	100	109	121	142	178	252	479
4.0	124	131	142	158	186	233	330	623
4.5	157	165	179	200	235	294	417	788
5.0	193	203	221	247	289	363	514	972
5.5	233	246	267	299	350	439	622	1,176
6.0	278	293	318	356	417	523	741	1,400
6.5	326	344	373	417	489	614	869	1,643
7.0	378	399	432	484	568	712	1,008	1,906
7.5	434	458	496	556	652	817	1,158	2,189
8.0	493	521	564	632	741	929	1,317	2,491
8.5	557	588	637	713	837	1,049	1,486	2,819
9.0	625	659	715	800	938	1,176	1,667	3,160
9.5	697	735	797	892	1,046	1,312	1,857	3,521
10.0	772	814	883	988	1,159	1,453	2,058	3,903
10.5	851	897	973	1,089	1,278	1,601	2,269	4,304
11.0	933	984	1,067	1,095	1,401	1,754	2,489	4,722
11.5	1,020	1,076	1,167	1,307	1,532	1,920	2,721	5,162
12.0	1,111	1,172	1,270	1,423	1,668	2,091	2,963	5,621
12.5	1,205	1,271	1,377	1,543	1,810	2,268	3,215	6,099
13.0	1,304	1,375	1,490	1,669	1,959	2,453	3,478	6,597
13.5	1,406	1,483	1,507	1,800	2,112	2,644	3,750	7,113
14.0	1,513	1,595	1,729	1,936	2,271	2,846	4,033	7,649
14.5	1,662	1,711	1,854	2,076	2,436	3,053	4,325	8,203
15.0	1,736	1,832	1,985	2,223	2,608	3,268	4,630	8,779
15.5	1,854	1,956	2,119	2,374	2,784	3,489	4,944	9,378
16.0	1,975	2,084	2,257	2,529	2,966	3,718	5,268	8,986
16.5	2,101	2,217	2,401	2,690	3,155	3,954	5,603	10,625
17.0	2,230	2,353	2,549	2,856	3,349	4,197	5,946	11,282
17.5	2,364	2,493	2,701	3,027	3,549	4,448	6,302	11,954
18.0	2,500	2,637	2,857	3,202	3,754	4,706	6,667	12,645
18.5	2,641	2,785	3,018	3,382	3,965	4,971	7,043	13,358
19.0	2,785	2,938	3,183	3,568	4,183	5,243	7,429	14,091
19.5	2,934	3,095	3,353	3,759	4,406	5,621	7,825	14,842
20.0	3,087	3,255	3,527	3,953	4,634	5,809	8,231	15,613
20.5	3,243	3,420	3,706	4,151	4,869	6,103	8,648	16,403
21.0	3,403	3,589	3,889	4,356	5,109	6,405	9,075	17,213
21.5	3,567	3,762	4,076	4,565	5,355	6,713	9,512	18,042
22.0	3,734	3,939	4,268	4,780	5,608	7,029	9,959	18,891
22.5	3,906	4,120	4,464	5,000	5,866	7,352	10,417	19,760

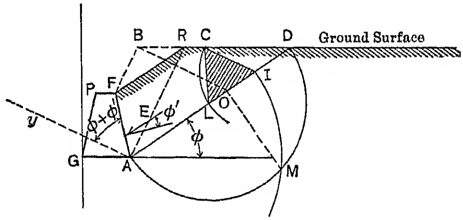
TABLE 37 (*Concluded*)

AMOUNT OF MATERIAL IN CUBIC YARDS PER 100 LINEAR FEET OF CUT ON SLOPING GROUND

Side Slopes 2 to 1

Depth of Center Cut, in Feet	Surface Slope of Ground in per Cent							
	10	15	20	25	30	35	40	45
23.0	4,082	4,306	4,665	5,225	6,130	7,683	10,886	20,648
23.5	4,262	4,495	4,879	5,454	6,399	8,021	11,364	21,555
24.0	4,445	4,688	5,080	5,689	6,675	8,365	11,853	22,482
24.5	4,631	4,885	5,293	5,928	6,955	8,715	12,352	23,428
25.0	4,823	5,087	5,512	6,174	7,242	9,075	12,861	24,395
25.5	5,018	5,292	5,734	6,424	7,533	9,442	13,380	25,381
26.0	5,216	5,500	5,960	6,678	7,830	9,817	13,909	26,385
26.5	5,419	5,714	6,192	6,938	8,135	10,199	14,450	27,410
27.0	5,625	5,932	6,428	7,202	8,445	10,587	15,000	28,454
27.5	5,835	6,154	6,669	7,471	8,762	10 983	15,561	29,518
28.0	6,049	6,380	6,813	7,746	9,083	11,386	16,132	30,600
28.5	6,268	6,611	7,163	8,027	9,411	11,798	16,714	31,704
29.0	6,490	6,845	7,417	8,311	9,744	12,215	17,305	32,826
29.5	6,715	7,083	7,674	8,598	10,082	12,638	17,906	33,967
30.0	6,945	7,328	7,937	8,891	10,428	13,071	18,519	35,129
30.5	7,178	7,572	8,204	9,188	10,779	13,510	19,141	36,309
31.0	7,415	7,821	8,475	9,491	11,135	13,954	19,773	37,509
31.5	7,657	8,075	8,750	9,801	11,497	14,410	20,417	38,729
32.0	7,902	8,333	9,030	10,115	11,865	14,871	21,071	39,968
32.5	8,150	8,596	9,314	10,434	12,238	15,339	21,735	41,227
33.0	8,403	8,863	9,603	10,758	12,617	15,815	22,409	42,506
33.5	8,660	9,133	9,896	11,086	13,002	16,298	23,093	43,803
34.0	8,920	9,408	10,194	11,419	13,393	16,788	23,787	45,120
34.5	9,184	9,687	10,496	11,757	13,791	17,286	24,492	46,457
35.0	9,452	9,970	10,802	12,100	14,194	17,791	25,207	47,813
35.5	9,724	10,257	11,113	12,447	14,602	18,302	25,932	49,189
36.0	10,000	10,548	11,429	12,800	15,016	18,820	26,668	50,585
36.5	10,280	10,843	11,749	13,158	15,436	19,346	27,414	52,000
37.0	10,563	11,142	12,073	13,522	15,861	19,880	28,170	53,434
37.5	10,850	11,445	12,401	13,891	16,293	20,422	28,937	54,888
38.0	11,142	11,752	12,733	14,264	16,730	20,971	29,713	56,361
38.5	11,437	12,063	13,071	14,642	17,174	21,527	30,500	57,855
39.0	11,737	12,378	13,413	15,025	17,623	22,190	31,297	59,368
39.5	12,039	12,697	13,759	15,413	18,078	22,660	32,104	60,906
40.0	12,346	13,021	14,110	15,805	18,539	23,237	32,923	62,451
40.5	12,656	13,349	14,465	16,202	19,006	23,821	33,752	64,021
41.0	12,971	13,681	14,824	16,605	19,479	24,414	34,590	65,611
41.5	13,290	14,017	15,187	17,013	19,957	25,012	35,438	67,221
42.0	13,612	14,357	15,556	17,425	20,441	25,619	36,298	68,851
42.5	13,938	14,701	15,929	17,842	20,930	26,231	37,168	70,501
43.0	14,267	15,049	16,306	18,264	21,424	26,852	38,047	72,170
43.5	14,601	15,401	16,687	18,691	21,925	27,481	38,937	73,588
44.0	14,939	15,757	17,073	19,124	22,432	28,116	39,837	75,565

Retaining Walls and Beams.—Retaining walls and beams play a very important part in the design of irrigation structures. A simple graphical method of calculating earth pressures on retaining walls is described by Prof. William Cain in the Transactions of the American Society of Civil Engineers of June, 1911, from which the following is taken:



(1) $A F P G$ is a wall of any shape or dimensions.
(2) ϕ = Angle of repose of material.
(3) ϕ' = Angle of friction between material and wall.
(4) $F R D$ is the ground surface.
(5) Draw $R A$.
(6) Produce $D R$.
(7) Draw $F B$ parallel to $R A$.
(8) Draw $B O$ parallel to $A Y$.
(9) Describe the arc $A M D$ on $A D$.
(10) Draw $O M \perp$ to $A D$.
(11) With A as center, describe arc $M I$.
(12) Draw $I C$ parallel to $A Y$.
(13) Make $I L = I C$ and draw $C L$.
(14) The total pressure on one linear foot of wall is then equal to the area of the triangle $I C L$ multiplied by the weight of 1 cubic foot of the material.
(15) The point of application may be taken as at one-third $A F$ from A. The average pressure equals the total divided by $A F$. The maximum pressure equals twice the average.
(16) When $R D$ is parallel to $A D$ the formula for total pressure on $A F$ is:

$$E = \tfrac{1}{2} e h^2 \frac{\cos^2 \phi}{\cos \phi'}$$

e = wt. of 1 cu. ft. of material
h = height of wall

See Fig. 45 for total earth pressures on walls without surcharge based on equivalent water pressure.

Formulas for Maximum Bending Moments in Beams.—The variation of pressures on any submerged wall due to water or earth is generally triangular or trapezoidal, that is, the loading at one end is greater than at the other. In the following list are given the principal formulas for calculating the bending moments due to uniform loads, triangular loads, and trapezoidal loads. The bending moments are given in inch-pounds; the loading is in pounds per linear foot; and the span is in feet.

Uniform loading:

W = load on beam in pounds per linear foot.
l = span in feet.
M = bending moment in inch-pounds.

(1) $M = 1.5\ W\ l^2$, for a simple beam.
(2) $M = W\ l^2$, for negative bending moment at the supports of a fixed beam.
(3) $M = 0.5\ W\ l^2$ for the positive bending moment at the center of a fixed beam.
(4) $M = 6\ W\ l^2$, for a cantilever beam.

Triangular loading:

P = load at end of beam in pounds per linear foot.

(5) $M = 0.77\ P\ l^2$, for a simple beam.
(6) $M = 0.6\ P\ l^2$, for the maximum negative bending moment at the more heavily loaded end of a fixed beam.
(7) $M = 0.26\ P\ l^2$, for the maximum positive bending moment between supports of a fixed beam.
(8) $M = 2\ P\ l^2$, for a cantilever beam having the base of triangular load at supported end.

Trapezoidal loading:

W_1 = load in pounds per linear foot at lightly loaded end.

P_1 = load in pounds per linear foot at heavily loaded end.

(9) $M = \frac{W_1}{2}(l\,x - x^2) + \frac{l\,x}{6}(P_1 - W_1)\left(1 - \frac{x^2}{l^2}\right)$ for a simple beam, the point of maximum bending moment being at

$$x = \frac{l}{P_1 - W_1}\left(-W_1 + \sqrt{W_1^2 + W_1(P_1 - W_1) + \tfrac{1}{3}(P_1 - W_1)^2}\right)$$

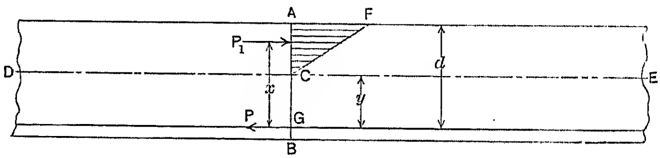
(10) $M = W_1 l^2 + 0.6\,(P_1 - W_1)\,l^2$, for the maximum negative moment at the heavily loaded support of a fixed beam.

(11) $M = 0.5\,W_1\,l^2 + 0.26\,(P_1 - W_1)\,l^2$, for the maximum positive (approximate) moment between supports of a fixed beam.

(12) $M = 6\,W_1\,l^2 + 2\,(P_1 - W_1)\,l^2$, for cantilever beams with the heavier loading at the supported end.

Table 38 gives the bending moments in thousands inch-pound units in beams one foot wide for triangular loading, that is: for loads varying uniformly from O pounds per linear foot at one end to P pounds per linear foot at the other end, due to water and earth pressures. ϕ is the angle of repose of the earth and θ is the slope of surface of ground back of the wall. The face of the wall against which the pressure acts is assumed to be vertical and the angle of friction between earth and wall is not considered.

Formulas for Reinforced Concrete Design.—The theory of the design of a rectangular concrete beam reinforced on one side may be illustrated by the following diagram:



Any section A-B of a reinforced concrete beam subjected to a bending moment has acting on it the forces P, representing the total stress in the steel, and P_1, representing the total

TABLE 38

BENDING MOMENTS IN THOUSANDS OF INCH-POUNDS IN BEAMS ONE FOOT WIDE UNDER LOADS VARYING UNIFORMLY FROM 0 POUNDS PER LINEAR FOOT AT ONE END TO P POUNDS PER LINEAR FOOT AT THE OTHER END DUE TO WATER AND EARTH PRESSURES COMPUTED FROM THE FORMULAS GIVEN BELOW.

SIMPLE BEAMS

$M = \frac{1}{27}\sqrt{3}\ Pl^2 \times 0.012 = 0.00077\ Pl^2.$

Load		P \ l	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Water		$62.5 \times l$	3.1	6.0	10.4	16.5	24.6	35.1	48.1	64.0	83.1	106	132	162	197	236	281	330	385
Earth $\phi = 26°$ 2 to 1	$\theta = 0°$	$39.1 \times l$	1.9	3.8	6.5	10.3	15.4	21.9	30.1	40.1	52.0	66.1	82.6	102	123	148	175	206	241
	$\theta = 15°$	$43.3 \times l$	2.1	4.2	7.2	11.4	17.1	24.3	33.3	44.4	57.6	73.2	91.4	113	137	164	194	229	267
	$\theta = 20°$	$47.9 \times l$	2.3	4.6	8.0	12.6	18.9	26.9	36.9	49.1	63.7	81.0	101	124	151	181	215	253	295
	$\theta = 26°$	$80.7 \times l$	4.0	7.8	13.4	21.3	31.8	45.3	62.1	82.7	107	136	170	210	254	305	362	426	497
Earth $\phi = 34°$ $1\frac{1}{2}$ to 1	$\theta = 0°$	$28.3 \times l$	1.4	2.7	4.7	7.5	11.1	15.9	21.8	29.0	37.6	47.9	59.8	73.5	89.3	107	127	149	174
	$\theta = 20°$	$33.8 \times l$	1.7	3.3	5.6	8.9	13.3	19.0	26.0	34.6	45.0	57.2	71.4	87.8	107	128	152	179	208
	$\theta = 26°$	$39.8 \times l$	2.0	3.8	6.6	10.5	15.7	22.3	30.6	40.8	52.9	67.3	84.1	103	125	151	179	210	245
	$\theta = 30°$	$47.7 \times l$	2.3	4.6	7.9	12.6	18.8	26.8	36.7	48.9	63.5	80.7	101	124	150	180	214	252	294
	$\theta = 34°$	$68.9 \times l$	3.4	6.6	11.5	18.2	27.1	38.7	53.0	70.6	91.6	117	145	179	217	261	309	364	424

Pressures on which this table is based were calculated from Rankine's formula.

ϕ = angle of repose of back-filling material.
θ = slope of surface of back-filling material.

TABLE 38 (*Concluded*)

BEAMS WITH FIXED ENDS

$M_1 = (\frac{1}{10}\sqrt{\frac{1}{10}} - \frac{1}{30})Pl^2 \times 0.012 = 0.000257\ Pl^2$ at center. $M_2 = -\frac{1}{20}\ Pl^2 \times 0.012 = -\ 0.0006\ Pl^2$ at loaded end.

Load		P \ l	4		6		8		10		12		14		16		18		20	
			M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2	M_1	M_2
Water		$62.5 \times l$	1.0	2.4	3.5	8.1	8.2	19.2	16.1	37.5	27.8	64.8	44.1	103	65.8	154	93.7	219	124	300
Earth $\phi = 26°$ 2 to 1	$\theta = 0°$	$39.1 \times l$	0.6	1.5	2.2	5.1	5.1	12.0	10.0	23.5	17.4	40.5	27.6	64.4	41.2	96.1	58.6	137	80.4	188
	$\theta = 15°$	$43.3 \times l$	0.7	1.7	2.4	5.6	5.7	13.3	11.1	26.0	19.3	44.9	30.5	71.2	45.6	106	64.9	151	89.0	208
	$\theta = 20°$	$47.9 \times l$	0.8	1.8	2.7	6.2	6.3	14.7	12.3	28.8	21.3	49.7	33.8	78.8	50.4	118	71.8	168	98.5	230
	$\theta = 26°$	$80.7 \times l$	1.3	3.1	4.5	10.5	10.6	24.8	20.7	48.4	35.8	83.6	56.9	133	85.0	198	121	282	166	387
Earth $\phi = 34°$ $1\frac{1}{2}$ to 1	$\theta = 0°$	$28.3 \times l$	0.5	1.1	1.6	3.7	3.7	8.7	7.3	17.0	12.6	29.3	20.0	46.6	29.8	69.6	42.4	99.0	58.2	136
	$\theta = 20°$	$33.8 \times l$	0.6	1.3	1.9	4.4	4.4	10.4	8.7	20.6	15.0	35.0	23.8	55.6	35.6	83.1	50.6	118	69.5	162
	$\theta = 26°$	$39.8 \times l$	0.7	1.5	2.2	5.2	5.2	12.2	10.2	23.9	17.7	41.3	28.1	65.5	41.9	97.8	59.6	139	81.8	191
	$\theta = 30°$	$47.7 \times l$	0.8	1.8	2.6	6.2	6.3	14.7	12.3	28.6	21.2	49.5	33.6	78.5	50.2	117	71.5	167	98.1	229
	$\theta = 34°$	$68.9 \times l$	1.1	2.6	3.8	8.9	9.1	21.2	17.7	41.4	30.6	71.4	48.6	113	65.4	169	103	241	142	331

$M = \frac{1}{6}\ Pl^2 \times 0.012 = 0.002\ Pl^2$

CANTILEVER BEAMS

Load		P \ l	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Water		$62.5 \times l$	8.0	15.6	27.0	42.9	64.0	91.1	125	166	216	275	343	422	512	614	729	858	1000
Earth $\phi = 26°$ 2 to 1	$\theta = 0°$	$39.1 \times l$	5.0	9.8	16.9	26.8	40.0	57.0	78.2	104	135	172	215	264	320	384	456	536	626
	$\theta = 15°$	$43.3 \times l$	5.5	10.8	18.7	29.7	44.3	63.1	86.6	115	150	190	238	292	355	426	505	594	693
	$\theta = 20°$	$47.9 \times l$	6.1	12.0	20.7	32.9	49.0	69.8	95.8	128	166	211	263	323	392	471	559	657	766
	$\theta = 26°$	$80.7 \times l$	10.3	20.2	34.9	55.4	82.6	118	161	215	279	355	443	544	661	793	941	1107	1292
Earth $\phi = 34°$ $1\frac{1}{2}$ to 1	$\theta = 0°$	$28.3 \times l$	3.6	7.1	12.2	19.4	29.0	41.3	56.6	75.4	97.8	124	155	191	232	278	330	388	453
	$\theta = 20°$	$33.8 \times l$	4.3	8.5	14.6	23.2	34.6	49.3	67.6	90.0	117	149	186	228	277	332	394	464	541
	$\theta = 26°$	$39.8 \times l$	5.1	9.9	17.2	27.3	40.7	58.0	79.6	106	138	175	218	269	326	391	464	546	637
	$\theta = 30°$	$47.7 \times l$	6.1	11.9	20.6	32.7	48.8	69.5	95.4	127	165	210	262	322	391	469	556	654	764
	$\theta = 34°$	$68.9 \times l$	8.8	17.2	29.8	47.3	70.5	100	138	184	238	303	378	465	564	677	803	945	1103

stress in the concrete. The stress in the steel is concentrated at one point, but the compressive stress in concrete (tensile stress from C to B is neglected, as it has no influence on the ultimate, or even the working strength of the beam) varies from zero at C to a maximum at A, the rate of increase being uniform from C to A. The summation of these stresses is represented by $P_1 = P$, whose point of application is one-third of $A\,C$ below A. The resisting moment of the section, therefore, is equal to $P\,x$ or $P_1\,x$, and this must be equal to the bending moment, or $M = P\,x = P_1\,x$.

The value of x for a given beam depends upon the location of the neutral axis which varies with different percentages of steel and with the quality of the concrete. This variation is slight for ordinary percentages of steel and grades of concrete used in practice and the neutral axis may be assumed to be located at 0.39 d below the top of the beam. The point of application of P_1, then, is $\frac{0.39\,d}{3} = 0.13\,d$ below the top of the beam and the lever arm x of internal stresses is $d - .13\,d = .87\,d$, or $\frac{7}{8}\,d$, and the resisting moment is $\frac{7}{8}\,d\,P$.

Therefore, $$M = .\tfrac{7}{8}\,d\,P$$

and $$P = \frac{8\,M}{7\,d} = P_1$$

If f_s represents the intensity of working stress in the steel, the area of steel required is

$$A = \frac{P}{f_s} = \frac{8\,M}{7\,d\,f_s}$$

The shifting of the neutral axis has a greater influence on the fiber stress in the concrete than on the stress in the steel. On the assumption that the coefficient of elasticity of concrete is equal to 2,000,000, which corresponds to a good grade of concrete, the position of neutral axis will vary from .3 d to .48 d below the top of beam for percentages of steel varying from 0.4 to 1.5, the ordinary range of practice.

With this variation in the position of the neutral axis, the maximum fiber stress in the concrete varies from $f_c = \frac{7.5\,M}{b\,d^2}$

for 0.4 per cent steel to $f_c = \frac{5\,M}{b\,d^2}$ for 1.5 per cent steel. These equations apply only to working stresses of about one-fourth the ultimate. Beyond this point the variation of stresses in the concrete becomes parabolic, resulting in a different set of equations.

For approximate design, Turneaure and Maurer give the following formulas:

M = bending moment in inch-pounds
f_s = unit stress in steel
f_c = maximum fiber stress in concrete
b = width of beam
d = depth of beam above plane of steel

$$p = \text{ratio of steel area to concrete area} = \frac{A}{b\,d}$$

for $\quad p = \frac{3}{16}\frac{f_c}{f_s}$

$$(1) \quad b\,d^2 = \frac{8\,M}{7 f_s\,p} \quad \text{and} \quad b\,d^2 = \frac{6\,M}{f_c} \quad (2)$$

If a value of p greater than $\frac{3}{16}\frac{f_c}{f_s}$ is used, then equation (2) should be used to determine b and d. If a value of p less than $\frac{3}{16}\frac{f_c}{f_s}$ is used, equation (1) should be used for determining b and d.

If equation (2) is used, the unit stress in the steel is given very closely by equation (1) in all cases, but if equation (1) is used for determining b and d equation (2) will not give the unit stress in the concrete unless $p = \frac{3}{16}\frac{f_c}{f_s}$. For other values of p the unit stress in the concrete may range approximately from $f_c = \frac{7.5\,M}{b\,d^2}$ for p = 0.4 per cent to $f_c = \frac{5\,M}{b\,d^2}$ for p = 1.5 per cent.

Example of Use of Above Formulas.—A concrete beam has a bending moment of 50,000 inch-pounds, f_s is to be not greater than 12,000 and f_c is to be not greater than 500. Determine b and d and the area of steel required. In order to have $f_s = 12{,}000$ and $f_c = 500$,

$$p = {}^3\!/_{16}\frac{f_c}{f_s} = {}^3\!/_{16} \times \frac{5{,}000}{12{,}000} = .0078$$

$$= 0.78 \text{ per cent.}$$

From (1) $$b\,d^2 = \frac{8 \times 50{,}000}{7 \times 12{,}000 \times .0078} = 611$$

From (2) $$b\,d^2 = \frac{6 \times 50{,}000}{500} = 600$$

$$\text{If } b = 8 \text{ inches } d = \sqrt{\frac{600}{8}} = 8.7 \text{ inches}$$

Now, if it were desired to use 1.00 per cent of steel, equation (2) would be used and we would have $b\,d^2$ equal to 600 as before, while the stress in the concrete would be between 500 and 410, $\left(= \frac{5\,M}{b\,d^2}\right)$ or roughly, 470,* and the stress in the steel would be

$$f_s = \frac{8\,M}{7\,p\,b\,d^2} = \frac{8 \times 50{,}000}{7 \times .01 \times 600} = 9{,}500$$

If only 0.5 per cent steel were used, equation (1) would be used for finding b and d:

$$b\,d^2 = \frac{8 \times 50{,}000}{7 \times 12{,}000 \times .005} = 950$$

If $$b = 8 \quad d = \sqrt{\frac{950}{8}} = 11 \text{ inches}$$

* The stress of 500 corresponds to a percentage of steel of .78 and 410 $\left(= \frac{5\,M}{b\,d^2}\right)$ corresponds to a percentage of 1.5 as above stated. The assumption of a linear variation between these limits gives a stress, corresponding to 1.0 per cent steel, of $500 - \left[\frac{.22}{.72}(500 - 410)\right] = 470$ pounds per square inch.

In this case, the stress in the steel would be 12,000 pounds per square inch, as assumed, but the stress in concrete would be between 500 and $\frac{7.5\,M}{b\,d^2} = \frac{7.5 \times 50{,}000}{950} = 395$; in fact, it would be very near the latter figure—roughly, 370.

By means of the above equations, approximate calculations can be rapidly made without the use of tables, diagrams, or complicated formulas, and they will be found to serve admirably for ordinary beam problems when tables or diagrams are not available.

Fig. 40* is a convenient diagram for proportioning reinforced concrete beams. This diagram is based on a ratio of coefficient of elasticity of steel to coefficient of elasticity of concrete of 15. Its values correspond closely with those obtained from the above equations.

Table 39* for round rods and **Table 40*** for square rods are convenient for use with this diagram in the design of walls and slabs.

Illustrative Examples.—The bending moment M in a beam is 50,000. Find the values of b, d, and p required to carry this when $f_c = 400$ and $f_s = 10{,}000$: Solution: At the intersection of the lines marked $f_c = 400$ and $f_s = 10{,}000$ we read the percentage of steel equals 0.75 and $M/b\,d^2 = 65 \therefore b\,d^2 = \frac{M}{65} = 770$. If $b = 8$ inches, $d = \sqrt{\frac{770}{8}} = 9.8$ inches from the top of beam to center of steel. Area of steel required $8 \times 9.8 \times .0075 = 0.59$ square inches, requiring 2 ⅝-inch round rods.

(2) The bending moment per linear foot on a concrete retaining wall is 75,000 inch-pounds. Find the thickness of wall and size and spacing of reinforcement rods required when $f_s = 12{,}000$ and $f_c = 500$. Solution: As before read from the diagram $\frac{M}{b\,d^2} = 84$ and $p = 0.8$.

$$\frac{M}{b\,d^2} = 84 = \frac{75{,}000}{b\,d^2}$$

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* Reproduced by permission from "Principles of Reinforced Construction," by Turneaure and Maurer, John Wiley & Sons, New York.

n = 15

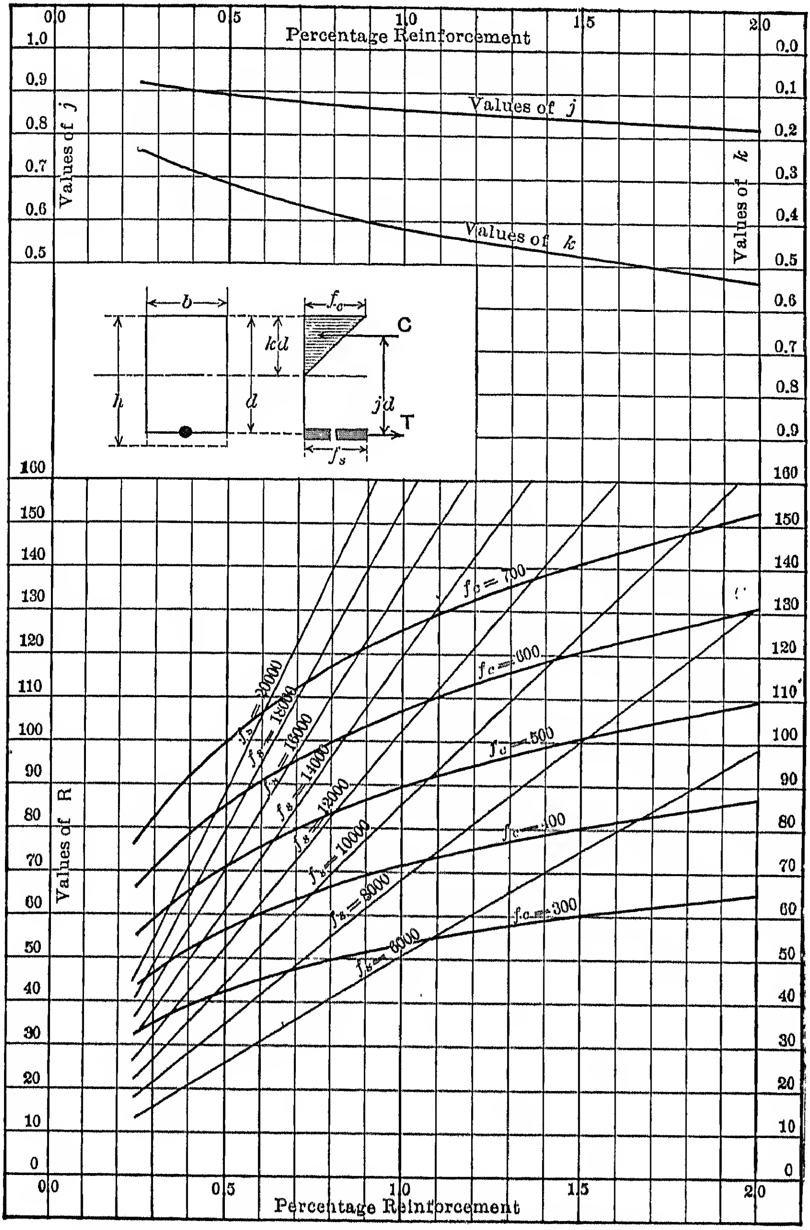

FIG. 40.—Coefficients of Resistance of Reinforced Concrete Beams.

$$R = \frac{M}{bd^2}$$

TABLE 39

AREAS, WEIGHTS, AND SPACING OF RODS

Round Rods

Size, Inches	Area, Square Inches	Circumference, Inches	Weight per Foot-Pounds	Sectional Area of Steel per Foot of Slab when Spaced as Follows:													
				2″	$2\frac{1}{2}$″	3″	$3\frac{1}{2}$″	4″	$4\frac{1}{2}$″	5″	$5\frac{1}{2}$″	6″	7″	8″	9″	10″	12″
$\frac{1}{4}$	.0491	.7854	.167	.29	.23	.20	.17	.15	.13	.12	.11	.10	.08	.07	.07	.06	.05
$\frac{5}{16}$	.0767	.9818	.261	.46	.36	.31	.26	.23	.20	.18	.17	.15	.13	.11	.10	.09	.08
$\frac{3}{8}$	.1104	1.1781	.376	.66	.53	.44	.38	.33	.29	.26	.24	.22	.19	.17	.15	.13	.11
$\frac{7}{16}$	.1503	1.3745	.511	.90	.72	.60	.51	.45	.40	.36	.33	.30	.26	.23	.20	.18	.15
$\frac{1}{2}$	.1963	1.5708	.668	1.18	.94	.78	.67	.59	.52	.47	.43	.39	.34	.29	.26	.24	.20
$\frac{9}{16}$	.2485	1.7672	.845	1.49	1.19	.99	.85	.75	.66	.60	.54	.50	.43	.37	.33	.30	.25
$\frac{5}{8}$	.3068	1.9635	1.043	1.84	1.47	1.23	1.05	.92	.82	.74	.67	.61	.53	.46	.41	.37	.31
$\frac{11}{16}$	.3712	2.1599	1.262	2.23	1.78	1.48	1.27	1.11	.99	.89	.81	.74	.64	.56	.49	.45	.37
$\frac{3}{4}$	.4418	2.3562	1.502	2.65	2.12	1.77	1.51	1.32	1.18	1.06	.96	.88	.76	.66	.59	.53	.44
$\frac{13}{16}$	.5185	2.5526	1.763	3.11	2.48	2.07	1.78	1.50	1.38	1.24	1.13	1.04	.89	.78	.69	.62	.52
$\frac{7}{8}$	.6013	2.7489	2.044	3.61	2.88	2.40	2.06	1.80	1.60	1.44	1.31	1.20	1.03	.90	.80	.72	.60
$\frac{15}{16}$	.6903	2.9453	2.347	4.14	3.31	2.76	2.37	2.07	1.84	1.66	1.51	1.38	1.18	1.03	.92	.83	.69
1	.7854	3.1416	2.670	4.71	3.77	3.14	2.69	2.36	2.09	1.88	1.71	1.57	1.35	1.18	1.05	.94	.78
$1\frac{1}{8}$	.9940	3.5343	3.380	5.96	4.77	3.98	3.41	2.98	2.65	2.39	2.17	1.99	1.70	1.49	1.33	1.19	.99
$1\frac{1}{4}$	1.2272	3.9270	4.172	7.36	5.89	4.91	4.21	3.68	3.27	2.95	2.68	2.45	2.10	1.84	1.64	1.47	1.23
$1\frac{3}{8}$	1.4849	4.3197	5.049	8.91	7.12	5.94	5.09	4.45	3.96	3.56	3.24	2.97	2.55	2.23	1.98	1.78	1.48
$1\frac{1}{2}$	1.7671	4.7124	6.008	10.60	8.48	7.07	6.06	5.30	4.71	4.24	3.86	3.53	3.03	2.65	2.36	2.12	1.77

TABLE 40

Areas, Weights, and Spacing of Rods

Square Rods

Size, Inches	Area, Square Inches	Perimeter, Inches	Weight per Foot, Pounds	Sectional Area of Steel per Foot of Slab when Spaced as Follows: 2″	2½″	3″	3½″	4″	4½″	5″	5½″	6″	7″	8″	9″	10″	12″
¼	.0625	1.00	.212	.37	.30	.25	.21	.19	.17	.15	.13	.12	.11	.10	.08	.07	.06
5/16	.0977	1.25	.332	.59	.47	.39	.33	.29	.26	.23	.21	.19	.17	.15	.13	.12	.10
⅜	.1406	1.50	.478	.84	.67	.56	.48	.42	.37	.34	.31	.28	.24	.21	.19	.17	.14
7/16	.1914	1.75	.651	1.15	.92	.77	.66	.57	.51	.46	.42	.38	.33	.29	.25	.23	.19
½	.2500	2.00	.850	1.50	1.20	1.00	.86	.75	.67	.60	.55	.50	.43	.37	.33	.30	.25
9/16	.3164	2.25	1.076	1.90	1.52	1.27	1.08	.95	.84	.76	.69	.63	.54	.47	.42	.38	.32
⅝	.3906	2.50	1.328	2.34	1.87	1.56	1.34	1.17	1.04	.94	.85	.78	.67	.59	.52	.47	.39
11/16	.4727	2.75	1.607	2.84	2.27	1.99	1.62	1.42	1.33	1.13	1.03	.94	.81	.71	.66	.57	.47
¾	.5625	3.00	1.913	3.37	2.70	2.25	1.93	1.69	1.50	1.35	1.23	1.12	.96	.84	.75	.67	.56
13/16	.6602	3.25	2.245	3.96	3.17	2.64	2.26	1.98	1.76	1.58	1.44	1.32	1.13	.99	.88	.79	.66
⅞	.7656	3.50	2.603	4.59	3.67	3.06	2.62	2.30	2.04	1.84	1.67	1.53	1.31	1.15	1.02	.92	.77
15/16	.8789	3.75	2.988	5.27	4.22	3.52	3.01	2.64	2.34	2.11	1.92	1.76	1.51	1.32	1.17	1.05	.88
1	1.0000	4.00	3.400	6.00	4.80	4.00	3.43	3.00	2.67	2.40	2.18	2.00	1.71	1.50	1.33	1.20	1.00
1⅛	1.2656	4.50	4.303	7.59	6.08	5.06	4.34	3.80	3.37	3.04	2.76	2.53	2.17	1.89	1.69	1.52	1.27
1¼	1.5625	5.00	5.313	9.37	7.50	6.25	5.36	4.69	4.17	3.75	3.41	3.12	2.68	2.34	2.08	1.87	1.56
1⅜	1.8906	5.50	6.428	11.34	9.08	7.56	6.48	5.67	5.04	4.54	4.12	3.78	3.24	2.84	2.52	2.27	1.89
1½	2.2500	6.00	7.650	13.50	10.80	9.00	7.71	6.75	6.00	5.40	4.91	4.50	3.86	3.37	3.00	2.70	2.25

$$\therefore b\,d^2 = \frac{75{,}000}{84} = 893$$

$$\text{Since } b = 12,\ d = \sqrt{\frac{893}{12}} = 8.6 \text{ inches}$$

Area of steel per foot of wall $12 \times 8.6 \times .008 = .83$ square inch. From Table 39 we read that ⅝-inch round rods spaced 4½ inches on centers will supply this area.

TABLE 41

QUANTITIES OF MATERIALS REQUIRED FOR ONE CUBIC YARD OF RAMMED CONCRETE, ASSUMING A BARREL OF 3.8 CUBIC FEET

Parts in Mix			Voids in Broken Stone or Gravel					
			45%*			40%†		
Cement	Sand	Stone	Cement	Sand	Stone	Cement	Sand	Stone†
			Bbl.	*Cu. Yd.*	*Cu. Yd.*	*Bbl.*	*Cu. Yd.*	*Cu. Yd.*
1	2	3½	1.68	0.47	0.83	1.61	0.45	0.79
1	2	4	1.57	0.44	0.88	1.50	0.42	0.84
1	2	4½	1.48	0.42	0.94	1.41	0.40	0.89
1	2½	3	1.66	0.58	0.70	1.60	0.56	0.68
1	2½	3½	1.55	0.55	0.76	1.49	0.52	0.73
1	2½	4	1.46	0.51	0.82	1.40	0.49	0.79
1	2½	4½	1.37	0.48	0.87	1.31	0.46	0.83
1	2½	5	1.30	0.46	0.92	1.24	0.44	0.87
1	3	5	1.22	0.52	0.86	1.17	0.49	0.82
1	3	5½	1.16	0.49	0.90	1.11	0.47	0.86
1	3	6	1.11	0.47	0.94	1.05	0.44	0.89
1	4	7	0.92	0.52	0.91	0.88	0.50	0.87
1	4	8	0.85	0.48	0.96	0.81	0.46	0.91

* For broken stone.
† For gravel or stone and gravel.

Timber Structures.—Various tables, etc., are given in the following pages which may be found useful in the design of timber structures. The formulas for bending moments are given on page 221. The common flexure formula for beams of any shape is:

$$S = \frac{M\,c}{I}$$

where S = stress on extreme fiber in pounds per square inch
M = bending moment in inch-pounds
c = distance from neutral axis to extreme fiber in ins.
I = moment of inertia in inches^4

TABLE 42

ALLOWABLE UNIT STRESSES AND WEIGHTS OF TIMBER

Kind of Timber	Tension	Compression			Shearing		Weight in Lbs. per Cubic Foot Dry*
		With Grain		Across Grain	With Grain	Across Grain	
		End Bearing	Columns Under 15 Diams.				
Factor of Safety	10	5	5	4	4	4	
White oak	1200	1400	1000	500	200	1000	46.4
White pine	700	1100	800	200	100	500	25.6
Southern long-leaf pine	1200	1400	1000	350	150	1250	38.1
Douglas fir	800	1200	900	200	130	....	32.1
Short-leaf yellow pine	900	1100	800	250	100	1000	38.4
Norway pine	800	1000	750	200	...	....	30.2
Spruce and eastern fir	800	1200	900	200	100	750	25.0
Hemlock	600	1100	800	150	100	600	26.4 to 32.3
Cypress	600	1000	750	200	...	....	29.8
Cedar	700	1100	750	200	100	400	23.1
Chestnut	850	....	800	250	150	500	41.0
Cal. redwood	700	....	800	150	100	....	26.2
Cal. spruce	....	....	800	...	...	....	25.0

* The weights of green or unseasoned timbers are 20 to 40 per cent greater.

The above unit stresses are recommended by the Association of Railway Superintendents of Bridges and Buildings. They are for unseasoned timber. For structures not subjected to impact, these stresses may safely be increased 25 per cent.

For columns having a length greater than fifteen times the least dimension, the safe end-bearing stress may be obtained by the following formula:

$$S_1 = S\left(1 - \frac{L}{5\,d}\right)$$

when S_1 = allowable compression in column
S = allowable end-bearing from table
L = length of column in feet
d = least side of column in inches

TABLE 43

VALUES OF $\frac{M}{S} = \frac{b\,d^2}{6 \times 12}$ FOR WOODEN BEAMS
(M is in foot-pounds)

Depth of Beam "d"	Width "b"												
	2	3	4	6	8	10	12	14	16	18	20	22	24	Round
3	0.25	0.38	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	0.22
4	0.44	0.67	0.89	1.33	1.78	2.22	2.67	3.11	3.55	4.00	4.44	4.89	5.33	0.53
6	1.00	1.50	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	1.77
8	1.78	2.67	3.55	5.33	7.11	8.89	10.67	12.44	14.22	16.00	17.78	19.55	21.33	4.20
10	2.78	4.17	5.56	8.33	11.11	13.89	16.67	19.44	22.22	25.00	27.78	30.55	33.33	8.20
12	4.00	6.00	8.00	12.00	16.00	20.00	24.00	28.00	32.00	36.00	40.00	44.00	48.00	14.18
14	5.44	8.17	10.89	16.33	21.78	27.22	32.67	38.11	43.56	49.00	54.44	59.89	65.33	22.50
16	7.11	10.67	14.22	21.33	28.44	35.56	42.67	49.78	56.89	64.00	71.11	78.22	85.33	33.51
18	9.00	13.50	18.00	27.00	36.00	45.00	54.00	63.00	72.00	81.00	90.00	99.00	108.0	47.75
20	11.11	16.67	22.22	33.33	44.44	55.56	66.67	77.78	88.89	100.0	111.1	122.2	133.3	65.40
22	13.44	20.17	26.89	40.33	53.78	67.22	80.67	94.11	107.6	121.0	134.4	147.9	161.3	87.30
24	16.00	24.00	32.00	48.00	64.00	80.00	96.00	112.0	128.0	144.0	160.0	176.0	192.0	113.8
30	25.00	37.50	50.00	75.00	100.00	125.0	150.0	175.0	200.0	225.0	250.0	275.0	300.0	221.0

Note.—The values in this table are for beams of full dimensions.

TABLE 44

Contents in Feet B.M. of Lumber

Size of Piece, Inches	Length, in Feet							
	10	12	14	16	18	20	22	24
2 x 4	6⅔	8	9⅓	10⅔	12	13⅓	14⅔	16
2 x 6	10	12	14	16	18	20	22	24
2 x 8	13⅓	16	18⅔	21⅓	24	26⅔	29⅓	32
2 x 10	16⅔	20	23⅓	26⅔	30	33⅓	36⅔	40
2 x 12	20	24	28	32	36	40	44	48
2 x 14	23⅓	28	32⅔	37⅓	42	46⅔	51⅓	56
2 x 16	26⅔	32	37⅓	42⅔	48	53⅓	58⅔	64
4 x 4	13⅓	16	18⅔	21⅓	24	26⅔	29⅓	32
4 x 6	20	24	28	32	36	40	44	48
4 x 8	26⅔	32	37⅓	42⅔	48	53⅓	58⅔	64
4 x 10	33⅓	40	46⅔	53⅓	60	66⅔	73⅓	80
4 x 12	40	48	56	64	72	80	88	96
4 x 14	46⅔	56	65⅓	74⅔	84	93⅓	102⅔	112
6 x 6	30	36	42	48	54	60	66	72
6 x 8	40	48	56	64	72	80	88	96
6 x 10	50	60	70	80	90	100	110	120
6 x 12	60	72	84	96	108	120	132	144
6 x 14	70	84	98	112	126	140	154	168
6 x 16	80	96	112	128	144	160	176	192
8 x 8	53⅓	64	74⅔	85⅓	96	106⅔	117⅓	128
8 x 10	66⅔	80	93⅓	106⅔	120	133⅓	146⅔	160
8 x 12	80	96	112	128	144	160	176	192
8 x 14	93⅓	112	130⅔	149⅓	168	186⅔	205⅓	224
10 x 10	83⅓	100	116⅔	133⅓	150	166⅔	183⅓	200
10 x 12	100	120	140	160	180	200	220	240
10 x 14	116⅔	140	163⅓	186⅔	210	233⅓	256⅔	280
10 x 16	133⅓	160	186⅔	213⅓	240	266⅔	293⅓	320
12 x 12	120	144	168	192	216	240	264	288
12 x 14	140	168	196	224	252	280	308	336
12 x 16	160	192	224	256	288	320	352	384
14 x 14	163⅓	196	228⅔	261⅓	294	326⅔	359⅓	392
14 x 16	186⅔	224	261⅓	298⅔	336	373⅓	410⅔	448

TABLE 45

Contents in Feet B.M. of Logs

Diam. of Log, Ins.	Length, in Feet							
	8	10	12	14	16	18	20	22
8	8	10	12	14	16	18	20	22
9	12½	16	18	22	25	28	31	34
10	18	23	27	32	36	41	46	50
11	24½	31	37	43	49	55	61	67
12	32	40	48	56	64	72	80	88
13	40½	50	61	71	81	91	101	111
14	50	62	75	88	100	112	125	137
15	60½	75	91	106	121	136	151	166
16	72	90	108	126	144	162	180	198
17	84½	105	126	148	169	190	211	235
18	98	122	147	171	196	220	245	269
19	112½	140	169	197	225	253	280	309
20	128	160	192	224	256	288	320	352
21	144½	180	217	253	289	325	361	397
22	162	202	243	283	324	364	404	445
23	179½	225	271	313	359	406	452	496
24	200	250	300	350	400	450	500	550
25	220½	275	331	386	441	496	551	606
26	242	302	363	423	484	544	605	666
27	265	330	397	463	530	596	661	726
28	288	360	432	504	576	648	720	792
29	312½	391	469	547	625	703	782	860
30	338	422	507	591	676	761	845	930
31	364½	456	547	638	729	820	912	1004
32	392	490	588	686	784	882	980	1078
33	421	526	631	736	842	946	1051	1155
34	450	562	675	787	900	1012	1125	1237
35	480½	601	721	841	961	1081	1202	1322
36	512	640	768	896	1024	1152	1280	1408
37	544½	681	817	953	1089	1225	1361	1497
38	578	723	867	1011	1156	1300	1446	1590
39	612½	765	918	1070	1225	1379	1530	1684
40	648	810	972	1134	1296	1458	1620	1782
41	684½	850	1027	1198	1369	1541	1711	1882
42	721	903	1083	1264	1442	1625	1805	1986
43	760½	952	1141	1331	1521	1711	1902	2091
44	800	1000	1200	1400	1600	1800	2000	2200
45	840½	1051	1261	1471	1681	1891	2102	2312
46	882	1103	1323	1544	1764	1985	2206	2426
47	924½	1156	1387	1618	1849	2080	2312	2542
48	968	1210	1452	1694	1936	2178	2420	2662
49	1012½	1265	1519	1772	2025	2278	2530	2784
50	1058	1322	1587	1850	2116	2380	2645	2909

TABLE 46

Spacing, in Inches, of Round Bars for Reinforced Concrete Pipe or Bands for Wood Stave Pipe Computed from the Formula

$$s = 2.307\,\frac{AS}{hR}. \quad S = 10{,}000$$

(See also Fig. 41.)

	h = 10		h = 15			h = 20			h = 25			h = 30			
D \ t	⅛	3/16	⅛	3/16	¼	⅛	3/16	¼	⅛	3/16	¼	⅛	3/16	¼	5/16
6	6	6	6	6	6	4¾	6	6	3¾	6	6	3	6	6	6
8	6	6	4¾	6	6	3½	6	6	2¾	6	6	2¼	5¼	6	6
10	5½	6	3¾	6	6	2¾	6	6	2¼	5	6	1¾	4¼	6	6
12	4¾	6	3	6	6	2¼	5¼	6	1¾	4¼	6	1½	3½	6	6
14	4	6	2½	6	6	2	4½	6	1½	3½	6	1¼	3	5¼	6
16	3½	6	2¼	5¼	6	1¾	4	6	1¼	3	5½	...	2½	4½	6
18	3	6	2	4½	6	1½	3½	6	1¼	2¾	5	...	2¼	4	6
20	2¾	6	1¾	4¼	6	1¼	3	5½	...	2½	4½	...	2	3¾	5¾
22	2½	5¾	1½	3¾	6	1¼	2¾	5	...	2¼	4	...	1¾	3¼	5¼
24	2¼	5¼	1½	3½	6	...	2½	4½	...	2	3¾	...	1¾	3	4¾
26	2	4¾	1¼	3¼	5¾	...	2¼	4¼	...	1¾	3½	...	1½	2¾	4½
28	2	4½	1¼	3	5¼	...	2¼	4	...	1¾	3¼	...	1½	2½	4
D \ t	⅛	¼	⅛	¼	⅜	⅛	¼	⅜	⅛	¼	⅜	⅛	¼	⅜	½
30	1¾	6	1¼	5	6	...	3¾	6	...	3	6	...	2½	5½	6
32	1¾	6	...	4½	6	...	3½	6	...	2¾	6	...	2¼	5¼	6
34	1½	6	...	4¼	6	...	3¼	6	...	2½	6	...	2	5	6
36	1½	6	...	4	6	...	3	6	...	2½	5½	...	2	4½	6
38	1½	5¾	...	3¾	6	...	2¾	6	...	2¼	5¼	...	1¾	4¼	6
40	1¼	5½	...	3¾	6	...	2¾	6	...	2¼	5	...	1¾	4¼	6
42	1¼	5¼	...	3½	6	...	2½	6	...	2	4¾	...	1¾	4	6
44	1¼	5	...	3¼	6	...	2½	5¾	...	2	4½	...	1½	3¾	6
46	1¼	4¾	...	3¼	6	...	2¼	5½	...	1¾	4¼	...	1½	3½	6
48	...	4½	...	3	6	...	2¼	5¼	...	1¾	4¼	...	1½	3½	6
50	...	4½	...	3	6	...	2¼	5	...	1¾	4	...	1½	3¼	6
52	...	4¼	...	2¾	6	...	2	4¾	...	1¾	3¾	...	1¼	3¼	5¾
54	...	4	...	2¾	6	...	2	4½	...	1½	3¾	...	1¼	3	5½
56	...	4	...	2½	6	...	2	4½	...	1½	3½	...	1¼	3	5¼
58	...	3¾	...	2½	5¾	...	1¾	4¼	...	1½	3½	...	1¼	2¾	5
60	...	3¾	...	2½	5½	...	1¾	4¼	...	1½	3¼	...	1¼	2¾	5
62	...	3½	...	2¼	5¼	...	1¾	4	...	1¼	3¼	...	...	2½	4¾
64	...	3½	...	2¼	5¼	...	1¾	3¾	...	1¼	3	...	...	2½	4½
66	...	3¼	...	2¼	5	...	1½	3¾	...	1¼	3	...	...	2½	4½
68	...	3¼	...	2	5	...	1½	3¾	...	1¼	3	...	...	2½	4¼
70	...	3¼	...	2	4¾	...	1½	3½	...	1¼	2¾	...	...	2¼	4¼
72	...	3	...	2	4½	...	1½	3½	...	1¼	2¾	...	...	2¼	4

This table is based on a stress in the steel of 10,000 # per square inch. For a unit stress of 12,000 multiply spacings taken from table by 1.2; for a unit stress of 15,000 multiply by 1.5, etc. The maximum allowable spacing is fixed at 6 inches and the minimum at 1 inch plus the diameter of the steel.

s = spacing of rods or bands, in inches.
S = unit stress in steel.
A = cross-sectional area of steel rod or band, in square inches.
h = head of water on center of pipe in feet.
R = inside radius of pipe, in inches.
t = diameter of steel rod or band, in inches.
D = inside diameter of pipe, in inches.

TABLE 46 (*Continued*)

	h = 35				h = 40				h = 45			
D \ t	⅛	$\frac{3}{16}$	¼	$\frac{5}{16}$	⅛	$\frac{3}{16}$	¼	$\frac{5}{16}$	⅛	$\frac{3}{16}$	¼	$\frac{5}{16}$
6	2½	6	6	6	2¼	5¼	6	6	2	4½	6	6
8	2	4½	6	6	1¾	4	6	6	1½	3½	6	6
10	1½	3½	6	6	1¼	3	5½	6	1¼	2¾	5	6
12	1¼	3	5¼	6	.....	2½	4¾	6	.....	2¼	4	6
14	.....	2½	4½	6	.....	2¼	4	6	.....	2	3½	5½
16	.....	2¼	4	6	.....	2	3½	5½	.....	1¾	3	4¾
18	.....	2	3½	5½	.....	1¾	3	4¾	.....	1½	2¾	4¼
20	.....	1¾	3¼	5	.....	1½	2¾	4¼	.....	1¼	2½	3¾
22	.....	1½	2¾	4½	.....	1¼	2½	4	.....	1¼	2¼	3½
24	.....	1½	2½	4	.....	1¼	2¼	3½	.....	.....	2	3¼
26	.....	1¼	2½	3¾	.....	.....	2	3¼	.....	.....	1¾	3
28	.....	1¼	2¼	3½	.....	.....	2	3	.....	.....	1¾	2¾
D \ t	⅛	¼	⅜	½	⅛	¼	⅜	½	⅛	¼	⅜	½
30	.....	2	4¾	6	.....	1¾	4¼	6	.....	1½	3¾	6
32	.....	2	4½	6	.....	1¾	4	6	.....	1½	3½	6
34	.....	1¾	4¼	6	.....	1½	3¾	6	.....	1¼	3¼	5¾
36	.....	1¾	4	6	.....	1½	3½	6	.....	1¼	3	5½
38	.....	1½	3¾	6	.....	1½	3¼	5¾	.....	1¼	2¾	5¼
40	.....	1½	3½	6	.....	1¼	3	5½	.....	1¼	2¾	5
42	.....	1½	3¼	6	.....	1¼	3	5¼	.....	.....	2½	4¾
44	.....	1¼	3¼	5¾	.....	1¼	2¾	5	.....	.....	2½	4½
46	.....	1¼	3	5½	.....	.....	2¾	4¾	.....	.....	2¼	4¼
48	.....	1¼	3	5¼	.....	.....	2½	4½	.....	.....	2¼	4
50	.....	1¼	2¾	5	.....	.....	2½	4½	.....	.....	2¼	4
52	.....	1¼	2¾	4¾	.....	.....	2¼	4¼	.....	.....	2	3¾
54	.....	.....	2½	4¾	.....	.....	2¼	4	.....	.....	2	3½
56	.....	.....	2½	4½	.....	.....	2¼	4	.....	.....	2	3½
58	.....	.....	2½	4¼	.....	.....	2	3¾	.....	.....	1¾	3¼
60	.....	.....	2¼	4¼	.....	.....	2	3¾	.....	.....	1¾	3¼
62	.....	.....	2¼	4	.....	.....	2	3½	.....	.....	1¾	3
64	.....	.....	2¼	4	.....	.....	2	3½	.....	.....	1¾	3
66	.....	.....	2	3¾	.....	.....	1¾	3¼	.....	.....	1½	3
68	.....	.....	2	3¾	.....	.....	1¾	3¼	.....	.....	1½	2¾
70	.....	.....	2	3½	.....	.....	1¾	3¼	.....	.....	1½	2¾
72	.....	.....	2	3½	.....	.....	1¾	3	.....	.....	1½	2¾

TABLE 46 (*Continued*)

	h = 50				h = 60				h = 70			
D \ t	3/16	1/4	5/16	3/8	3/16	1/4	5/16	3/8	3/16	1/4	5/16	3/8
6	4¼	6	6	6	3½	6	6	6	3	5¼	6	6
8	3	5½	6	6	3½	4¾	6	6	2¼	4	6	6
10	2½	4½	6	6	2	3¾	5¾	6	1¾	3¼	5	6
12	2	3¾	5¾	6	1¾	3	4¾	6	1½	2½	4	6
14	1¾	3½	5	6	1½	2½	4	6	1¼	2¼	3½	5
16	1½	2¾	4¼	6	1¼	2¼	3½	5¼	.....	2	3	4½
18	1¼	2½	3¾	5½	.....	2	3¼	4¾	.....	1¾	2¾	4
20	1¼	2¼	3½	5	.....	1¾	2¾	4¼	.....	1½	2½	3½
22	.....	2	3	4½	.....	1½	2½	3¾	.....	1¼	2¼	3¼
24	.....	1¾	2¾	4¼	.....	1½	2¼	3½	.....	1¼	2	3
26	.....	1¾	2½	3¾	.....	1¼	2¼	3¼	.....	1¼	1¾	2¾
28	.....	1½	2½	3½	.....	1¼	2	3	.....	.....	1¾	2½
D \ t	1/4	3/8	1/2	5/8	1/4	3/8	1/2	5/8	1/4	3/8	1/2	5/8
30	1½	3¼	6	6	1¼	2¾	5	6	.....	2¼	4¼	6
32	1¼	3	5½	6	.....	2½	4½	6	.....	2¼	4	6
34	1¼	3	5¼	6	.....	2½	4¼	6	.....	2	3¾	5¾
36	1¼	2¾	5	6	.....	2¼	4	6	.....	2	3½	5½
38	.....	2½	4¾	6	.....	2¼	3¾	6	.....	1¾	3¼	5¼
40	.....	2½	4½	6	.....	2	3¾	5¾	.....	1¾	3	5
42	.....	2¼	4¼	6	.....	2	3½	5½	.....	1½	3	4¾
44	.....	2¼	4	6	.....	1¾	3¼	5¼	.....	1½	2¾	4½
46	.....	2	3¾	6	.....	1¾	3¼	5	.....	1½	2¾	4¼
48	.....	2	3¾	5¾	.....	1¾	3	4¾	.....	1½	2½	4
50	.....	2	3½	5½	.....	1½	3	4½	.....	.....	2½	4
52	.....	1¾	3½	5¼	.....	1½	2¾	4½	.....	.....	2½	3¾
54	.....	1¾	3¼	5¼	.....	1½	2¾	4¼	.....	.....	2¼	3¾
56	.....	1¾	3	5	.....	1½	2½	4	.....	.....	2½	3½
58	.....	1¾	3	4¾	.....	.....	2½	4	.....	.....	2	3½
60	.....	1½	3	4½	.....	.....	2½	3¾	.....	.....	2	3¼
62	.....	1½	2¾	4½	.....	.....	2¼	3¾	.....	.....	2	3¼
64	.....	1½	2¾	4¼	.....	.....	2¼	3½	.....	.....	2	3
66	.....	1½	2¾	4¼	.....	.....	2¼	3½	.....	.....	1¾	3
68	.....	1½	2½	4	.....	.....	2	3¼	.....	.....	1¾	2¾
70	.....	.....	2½	4	.....	.....	2	3¼	.....	.....	1¾	2¾
72	.....	.....	2½	3¾	.....	.....	2	3¼	.....	.....	1¾	2¾

TABLE 46 (*Concluded*)

	h = 80				h = 90				h = 100			
D \ t	3/16	1/4	5/16	3/8	3/16	1/4	5/16	3/8	3/16	1/4	5/16	3/8
6	2½	4¾	6	6	2¼	4	6	6	2	3¾	5¾	6
8	2	3½	5½	6	1¾	3	4¾	6	1½	2¾	4¼	6
10	1½	2¾	4¼	6	1¼	2½	3¾	5½	1¼	2¼	3½	5
12	1¼	2¼	3½	5¼	.....	2	3¼	4½	.....	1¾	2¾	4¼
14	.....	2	3	4½	.....	1¾	2¾	4	.....	1½	2½	3½
16	.....	1¾	2¾	3¾	.....	1½	2¼	3½	.....	1¼	2	3
18	.....	1½	2¼	3½	.....	1¼	2	3	.....	1¼	1¾	2¾
20	.....	1¼	2	3	.....	1¼	1¾	2¾	.....	.....	1¾	2½
22	.....	1¼	2	2¾	.....	.....	1¾	2½	.....	.....	1½	2
24	.....	.....	1¾	2½	.....	.....	1½	2¼	.....	.....	1¼	2
26	.....	.....	1½	2¼	.....	.....	1½	2	.....	.....	1¼	1¾
28	.....	.....	1½	2¼	.....	.....	.....	2	.....	.....	1¼	1¾
D \ t	3/8	1/2	5/8	3/4	3/8	1/2	5/8	3/4	3/8	1/2	5/8	3/4
30	2	3¾	5¾	6	1¾	3¼	5¼	6	1½	3	4½	6
32	2	3½	5½	6	1¾	3	4¾	6	1½	2¾	4¼	6
34	1¾	3¼	5	6	1½	2¾	4½	6	1½	2½	4	6
36	1¾	3	4¾	6	1½	2¾	4¼	6	1¼	2½	3¾	5½
38	1½	3	4½	6	1½	2½	4	6	1¼	2¼	3½	5¼
40	1½	2¾	4¼	6	.....	2½	3¾	5½	1¼	2¼	3½	5
42	1½	2½	4	6	.....	2¼	3¾	5¼	.....	2	3¼	4¾
44	.....	2½	4	5¾	.....	2¼	3½	5	.....	2	3	4½
46	.....	2¼	3¾	5½	.....	2	3¼	4¾	.....	1¾	3	4¼
48	.....	2¼	3½	5¼	.....	2	3¼	4½	.....	1¾	2¾	4¼
50	.....	2¼	3½	5	.....	2	3	4½	.....	1¾	2¾	4
52	.....	2	3¼	4¾	.....	1¾	3	4¼	.....	1¾	2½	3¾
54	.....	2	3¼	4½	.....	1¾	2¾	4	.....	1½	2½	3¾
56	.....	2	3	4½	.....	1¾	2¾	4	.....	1½	2½	3½
58	.....	1¾	3	4¼	.....	1½	2½	3¾	.....	1½	2¼	3½
60	.....	1¾	2¾	4¼	.....	1½	2½	3¾	.....	1½	2¼	3¼
62	.....	1¾	2¾	4	.....	1½	2½	3½	.....	.....	2¼	3¼
64	.....	1¾	2¾	3¾	.....	1½	2¼	3½	.....	.....	2	3
66	.....	1½	2½	3¾	.....	1½	2¼	3¼	.....	.....	2	3
68	.....	1½	2½	3½	.....	.....	2¼	3¼	.....	.....	2	3
70	.....	1½	2½	3½	.....	.....	2¼	3¼	.....	.....	2	2¾
72	.....	1½	2¼	3½	.....	.....	2	3	.....	.....	1¾	2¾

For rectangular beams $c = \dfrac{d}{2}$ and $I = \dfrac{b\,d^3}{12}$ and the formula becomes $S = \dfrac{6\,M}{b\,d^2}$. The values of c and I for other shapes of cross-section may be found in any standard pocket-book.

Table 43 is convenient for proportioning wooden beams. This table gives values of $\dfrac{b\,d^2}{6 \times 12} = \dfrac{M}{S}$, where M is in foot-pounds. To determine the size of a rectangular wooden beam, divide the bending moment in foot-pounds (equal to the bend-

ing moment in inch-pounds divided by 12) by the allowable stress in the wood; enter the diagram with the resulting quotient and read the depth and width of beam required. Example: A wooden beam is to be subjected to a bending moment of 50,000 foot-pounds; the allowable unit stress is 1,200 pounds per square inch; $\frac{M}{S} = \frac{50,000}{1,200} = 41.7$. From the table we find that a 12 x 16-inch beam gives a value of $\frac{M}{S}$ of 42.67. Other combinations of b and d also approximate the desired value of M/S, and the best combination to use must be decided on economical and practical considerations.

Table 46 gives the spacing, in inches, of round bars for pipes under pressure. It is intended primarily for the reinforcing bars of concrete pipes, but may also be used for determining the spacing of bands on wood pipe.

Fig. 41 gives similar data, but covers a much larger range, and is especially adapted to wood stave and concrete pipe of larger sizes and greater heads than are included in the table. This diagram gives without computation the spacing of bands or rods for heads from 20 to 200 feet, diameters of pipe from 18 to 120 inches, diameters of steel rods or bands from ⅜-inch to 1 inch, and stresses in steel from 10,000 to 15,000 pounds per square inch.

Example of Use of Diagram.—Given a 60-inch diameter wood pipe with a head of water of 150 feet. What size and spacing of bands are required, the working stress in bands to be 12,000 pounds per square inch? Solution: Enter the diagram at head = 150 feet; thence horizontally to the line for 60-inch pipe; thence down to the line for ⅜-inch band. Here it is noted that ⅜-inch bands would require a spacing of 0.57 inch. This spacing is impracticable, as is also the size of band for this pipe; we, therefore, follow diagonally to the right and note that ½-inch bands would require a spacing of 1 inch; continuing down diagonally we note that ⅝-inch bands would require a spacing of 1.56 inches and ¾-inch bands would require a spacing of 2.25 inches. If it is decided to use ¾-inch bands, we now follow down vertically to the line for 10,000

pounds per square inch stress; thence diagonally to the right to the line for 12,000 pounds per square inch stress and read the spacing 2.7 inches for ¾-inch bands, for a 60-inch pipe under a head of 150 feet, the working stress in the bands being 12,000 pounds per square inch. The formula on which the diagram is based is shown on the drawing.

Table 47 gives miscellaneous data in regard to the design and construction of wood pipe.

TABLE 47

MISCELLANEOUS DATA FOR WOOD PIPE

Economical Thickness of Staves

Machine-Banded Pipe		Continuous Pipe	
Diameter of Pipe, Inches	Thickness of Staves, Inches	Diameter of Pipe, Inches	Thickness of Staves, Inches
4	1 1/16	24	1½
6	1 1/16	36	1½
8	1⅛	48	1⅝
10	1⅛	60	1⅝ or 2⅛
12	1 3/16	72	2⅛ or 2½
14	1 3/16	84	2½ or 3⅛
16	1¼	96	2⅝ or 3⅛
18	1¼	108	3⅛ or 3½
20	1 5/16	120	3⅝ or 4
24	1 5/16	132	3⅝ or 4⅛
..	...	144	3⅝ or 4⅛

MAXIMUM CURVATURE ON WHICH SOME WOOD STAVE PIPES HAVE BEEN BUILT

Diameter, Feet	Thickness of Staves, Inches.	Radius of Curve, Feet	Kind of Curve	Ratio $\frac{\text{Radius of Curve}}{\text{Diameter of Pipe}}$
2.0	1½	58	....	29
2.5	1½	89	Horizontal	35
4.0	1⅝	83	Horizontal	21
4.7	1⅝	100	Vertical Concave	21
5.0	2	106	Vertical Convex	21
7.0	2⅝	296	Horizontal	43

These were about the sharpest curves the respective pipes would stand. Convex vertical curves (⌒) are easiest to build; concave vertical curves (‿) are next, and horizontal curves are the most difficult on account of the difficulty of applying the necessary pull to the pipe to throw it into the curve.

NOTE.—The above data on thickness of staves and maximum curvature were furnished by Mr. H. D. Coale, Chief Engineer, Pacific Tank and Pipe Company, Portland, Ore.

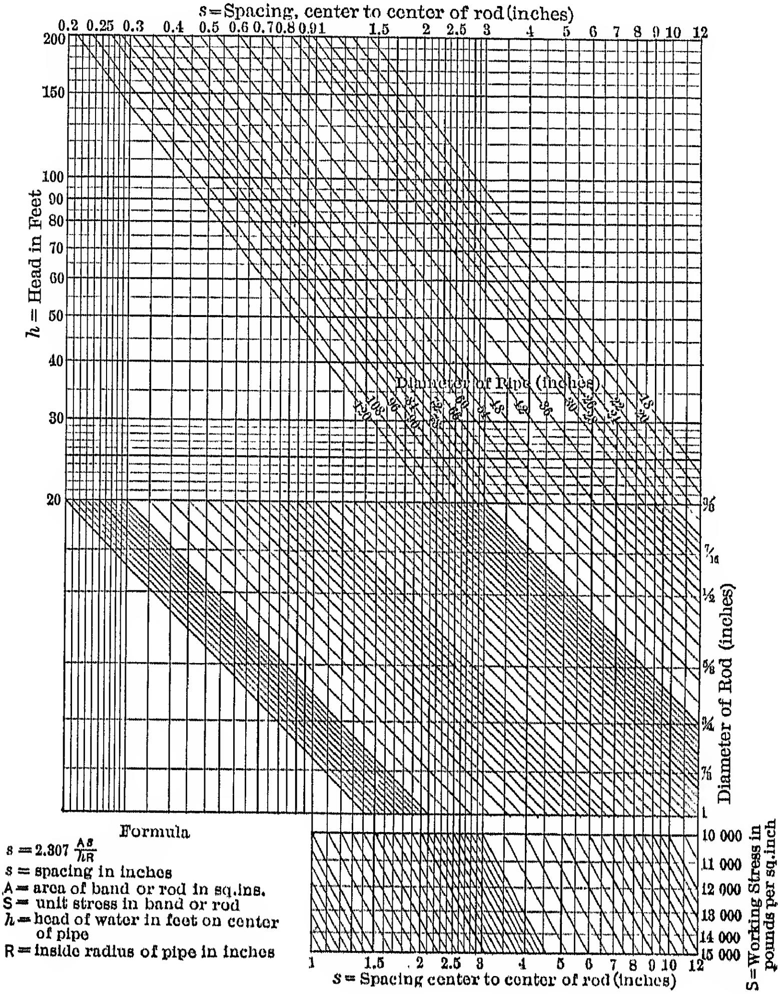

FIG. 41.—Spacing of Bands on Wood Stave Pipe and Reinforcement Rods in Concrete Pipe.

SIZE OF WIRE USUALLY USED FOR WINDING MACHINE-BANDED PIPE

Gage Number	Diameter, Inches	Area, Square Inches	Breaking Strength at 60,000 Lbs. per Sq. In.
0	.307	.074	4440
1	.283	.063	3774
2	.263	.054	3258
4	.225	.040	2388
6	.192	.029	1734
8	.162	.021	1236

Fig. 42 gives the thickness of steel pipe for three different efficiencies of joint, single riveted at 55 per cent, best double riveted at 72 per cent, and lock-bar pipe at 90 per cent. The lock-bar joint is capable of developing 100 per cent efficiency; but, due to occasional defects in material or workmanship on the lock-bars, an efficiency of 90 per cent is recommended for calculating the thickness. The thickness given in the diagram is the net thickness of steel required to withstand the given pressure at a unit stress in the steel of 16,000 pounds per square inch. It is customary to allow a slight excess of thickness to take care of the weakening by corrosion.

The following table * gives the greatest allowable depth of earth cover over steel pipe in feet. If a pipe is to be subjected to a greater pressure of earth than indicated in the table, the thickness must be increased or the pipe shell reinforced with angle irons or other suitable shapes.

DIAMETER OF PIPE

Thickness	30 Inches	36 Inches	42 Inches	48 Inches	54 Inches	60 Inches	72 Inches
$\frac{3}{16}$	5	..	..	..	..	..	..
$\frac{1}{4}$	8	5	4	3	..	..	..
$\frac{5}{16}$	12	9	6	5	4	3	2
$\frac{3}{8}$	18	12	9	7	6	4	3
$\frac{7}{16}$	25	17	12	9	8	6	4
$\frac{1}{2}$	..	22	16	12	10	8	6
$\frac{5}{8}$	..	..	..	..	15	12	9

* Figures taken from "American Civil Engineers' Pocket Book," Mansfield Merriman, Editor-in-Chief, John Wiley & Sons, New York City.

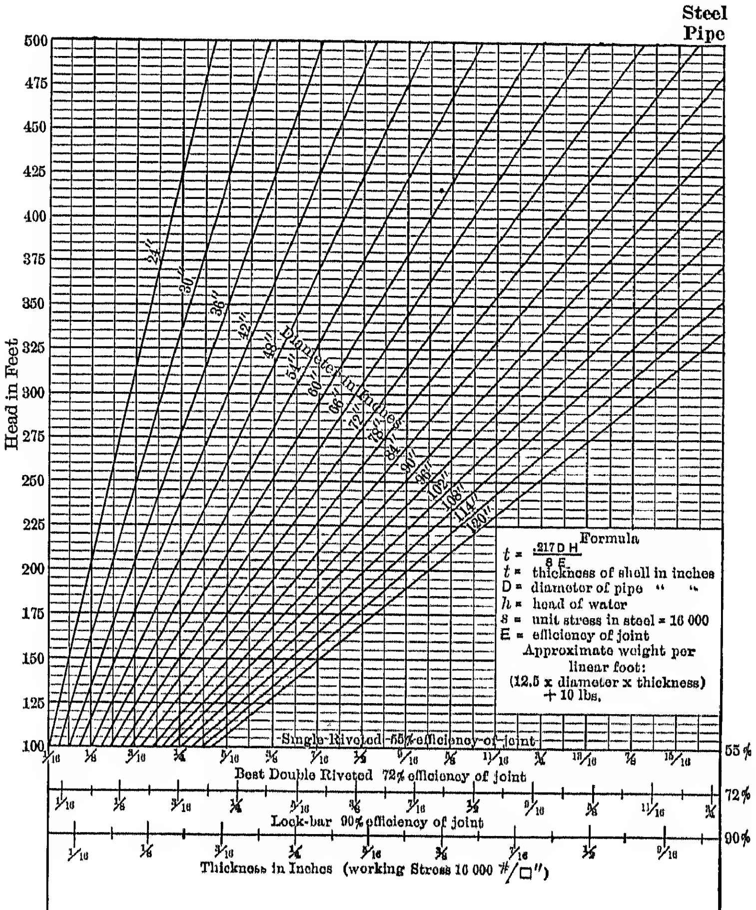

FIG. 42.—Thickness and Weight of Steel Pipe.

Example of Use of Diagram.—Given a 72-inch steel pipe for a power plant under a static head of 200 feet; an allowance of 50 per cent is to be made for water-ram and 10 per cent for corrosion, making the total head $(200 \times 1.60) = 320$ feet. Enter the diagram at a head of 320 feet, thence horizontally to the line for 72-inch pipe, then vertically down and read thickness slightly more than $\frac{9}{16}$ inch for single-riveted joint, slightly less than $\frac{7}{16}$ inch for double-riveted joint, and slightly more than $\frac{11}{32}$ inch for the lock-bar. Single riveting is seldom used for any but unimportant and temporary structures. Carrying the above example further, we note from the foregoing table that the $\frac{7}{16}$-inch shell will withstand a back-fill of 4 feet, and the $\frac{11}{32}$-inch shell will withstand between 2 and 3 feet. The approximate weight of the pipe is given by the formula shown in the diagram.

Table 48 gives the American Water Works Association Standards for thickness and weight of cast-iron pipe.

Table 49 gives the dimensions and weights of metal flumes as manufactured by the Hess Flume Co. of Denver, Col.

Fig. 43 gives the pressure of water in pounds per square inch, corresponding to heads up to 460 feet. The diagram contains two pairs of scales, those at top and left belonging to the upper line, and those at bottom and right belonging to the lower line.

Example 1.—What is the pressure corresponding to a head of 97 feet? Enter the diagram on the left at a head of 97 feet, thence horizontally to the upper line, thence vertically to the top scale and read 42 pounds per square inch.

Example 2.—What is the pressure corresponding to a head of 285 feet? Enter the diagram on the right at a head of 285 feet, thence horizontally to the lower line, thence vertically to the lower scale and read 124 pounds per square inch.

Fig. 44 gives the pressure of water in pounds per square foot for heads up to 380 feet. Its construction and manner of use are similar to Fig. 33.

Fig. 45 gives the total horizontal hydraulic pressure on a wall 1 foot long for heads up to 100 feet. This diagram is useful in the design of dams and retaining walls. For retaining walls for resisting earth pressures without surcharge, the pressures given by the diagram may be multiplied by 0.35 to 0.45 according to

the nature of the back-filling material, to obtain the total earth pressure. For pressures up to 30 feet, the lower line and lower scale are used. For pressures from 30 to 100 feet, the upper line and upper seals are used.

Example 1.—What is the total pressure on section of wall 10 feet long under a hydrostatic head of 75 feet? Enter the diagram on the left at a head of 75 feet, thence horizontally to the upper line, thence vertically to the upper scale, and read 176,000 pounds for a section of wall 1 foot long. For the 10-foot section the pressure will, therefore, be 1,760,000 pounds.

Example 2.—A retaining wall for earth is 25 feet high. What is the total earth pressure on a section of the wall 8 feet long? From the lower line of the diagram we read the hydrostatic pressure to be 19,500 pounds per linear foot of wall.

TABLE 48

CAST-IRON PIPE—THICKNESS AND WEIGHT

(American Water Works Association Standards)

Nominal Inside Diameter, Inches	Class A 100 Feet Head 43 Pounds Pressure			Class B 200 Feet Head 86 Pounds Pressure		
	Thickness, Inches	Weight per Foot	Weight per 12-Foot Length Laid	Thickness, Inches	Weight per Foot	Weight per 12-Foot Length Laid
4	.42	20.0	240	.45	21 7	260
6	.44	30.8	370	.48	33.3	400
8	.46	42.9	515	.51	47.5	570
10	.50	57.1	685	.57	63.8	765
12	.54	72.5	870	.62	82.1	985
14	.57	89.6	1075	.66	102.5	1230
16	.60	108.3	1300	.70	125.0	1500
18	.64	129.2	1550	.75	150.0	1800
20	.67	150.0	1800	.80	175.0	2100
24	.76	204.2	2450	.89	233.3	2800
30	.88	291.7	3500	1.03	333.3	4000
36	.99	391.7	4700	1.15	454.2	5450
42	1.10	512.5	6150	1.28	591.7	7100
48	1.26	666.7	8000	1.42	750.0	9000
54	1.35	800.0	9600	1.55	933.3	11200
60	1.39	916.7	11000	1.67	1104.2	13250
72	1.62	1283.4	15400	1.95	1545.8	18550
84	1.72	1633.4	19600	2.22	2104.2	25250

All weights include standard sockets.

TABLE 48 (*Concluded*)

CAST-IRON PIPE—THICKNESS AND WEIGHT

Nominal Inside Diameter, Inches	Class C, 300 Feet Head, 130 Pounds Pressure: Thickness, Inches	Class C: Weight per Foot	Class C: Weight per 12-Foot Length Laid	Class D, 400 Feet Head, 173 Pounds Pressure: Thickness, Inches	Class D: Weight per Foot	Class D: Weight per 12-Foot Length Laid
4	.48	23.3	280	.52	25.0	300
6	.51	35.8	430	.55	38.3	460
8	.56	52.1	625	.60	55.8	670
10	.62	70.8	850	.68	76.7	920
12	.68	91.7	1100	.75	100.0	1200
14	.74	116.7	1400	.82	129.2	1550
16	.80	143.8	1725	.89	158.3	1900
18	.87	175.0	2100	.96	191.7	2300
20	.92	208.3	2500	1.03	229.2	2750
24	1.04	279.2	3350	1.16	306.7	3680
30	1.20	400.0	4800	1.37	450.0	5400
36	1.36	545.8	6550	1.58	625.0	7500
42	1.54	716.7	8600	1.78	825.0	9900
48	1.71	908.3	10900	1.96	1050.0	12600
54	1.90	1141.7	13700	2.23	1341.7	16100
60	2.00	1341.7	16100	2.38	1583.3	19000
72	2.39	1904.2	22850	....	......	.....
84	....	......	.....	....	......	.....

All weights include standard sockets.

The total hydrostatic pressure on an 8-foot section, therefore, is 19,500 × 8 = 156,000 pounds. The earth pressure will equal from 0.35 to 0.45 of this, or 55,000 to 70,000 pounds, depending upon the nature of the back-fill, the material having the steepest angle of repose producing the smallest pressure, and *vice versa*.

Fig. 46 gives the theoretical horse-power of falling water. The diagram gives horse-powers directly for quantities up to 75 c. f. s. and falls up to 50 feet. The diagram may be used for higher values of quantity or fall by dividing by 10 before entering the diagram, and then multiplying the resulting power by 10.

Example 1.—What horse-power is produced by 45 c.f.s. of water falling 27 feet? Enter the diagram at the lower scale at $Q = 45$, thence vertically to the line representing a fall of 27 feet, thence horizontally to the scale at the left and read 138 horse-power.

TABLE 49

METAL FLUMES

Dimensions and Weights as Manufactured by Hess Flume Company, Denver, Col.*

Trade Number	Diameter		Area	Carrier Rods		Distance C-C of Joints, Inches	Total Weight of All Metal Work per Linear Foot of Flume						Weight of Rods, Collars, etc. per Section
	Feet	Inches	Square Feet	Diam., Inches	Spaced C-C In.		Gage	Weight	Gage	Weight	Gage	Weight	
12	0	8	.16	3/8	59¼	118½	24	1.448	22	1.704	20	1.952	2.747
15	0	10	.25	3/8	59¼	118½	24	1.776	22	2.088	20	2.408	3.086
18	1	0	.36	3/8	59¼	118½	24	2.104	22	2.488	20	2.864	3.435
24	1	3¼	.64	3/8	59¼	118½	24	2.792	22	3.296	20	3.80	4.415
30	1	7	1.00	3/8	59¼	118½	24	3.424	22	4.064	20	4.696	4.941
36	1	11	1.43	3/8	59¼	118½	24	4.080	22	4.848	20	5.608	5.691
42	2	3	1.93	3/8	34	34	22	6.708	20	7.632	18	9.486	4.236
48	2	7	2.54	3/8	34	34	22	7.626	20	8.688	18	10.806	4.738
60	3	2¼	3.97	3/8	34	34	22	9.444	20	10.770	18	13.590	5.668
72	3	9¾	5.73	3/8	34	34	22	11.262	20	12.846	18	16.026	6.598
84	4	5½	7.80	7/16	34	34	22	13.488	20	15.342	18	19.044	8.687
96	5	1	10.19	7/16	34	34	22	15.342	20	17.454	18	21.690	9.716
108	5	8¾	12.89	½	34	34	22	17.88	20	20.88	18	25.02	12.73
120	6	4¼	15.91	½	34	34	22	19.80	20	22.44	18	27.72	13.92
132	7	0	19.26	9/16	34	34	20	26.88	18	32.70	16	38.52	21.45
144	7	7¾	22.92	5/8	34	34	20	30.54	18	36.90	16	43.26	26.93
156	8	4	26.89	11/16	34	34	20	36.30	18	43.14	16	50.04	38.21
168	8	11	31.19	11/16	34	34	18	46.32	16	53.76	14	63.06	40.80
180	9	6¾	35.81	¾	34	34	18	51.06	16	58.98	14	68.88	47.57
192	10	2	40.74	13/16	34	34	16	64.50	14	75.12	12	96.24	55.25
204	10	9¾	45.99	7/8	34	33⅜	16	76.80	14	88.32	12	111.04	78.33
216	11	5½	51.56	7/8	34	33⅜	16	81.28	14	93.44	12	117.44	82.52
228	12	1	57.45	11/16	16 11/16	33⅜	16	89.92	14	102.72	12	128.64	97.24
240	12	8¾	63.66	¾	16 11/16	33⅜	16	98.56	14	112.32	12	139.52	113.67
252	13	4⅜	70.18	¾	16 11/16	33⅜	16	103.36	14	117.44	12	146.24	118.82
264	14	0	77.03	¾	16 11/16	33⅜	16	107.84	14	122.88	12	152.96	123.97
276	14	7¾	84.19	13/16	16 11/16	33⅜	16	117.76	14	133.12	12	164.48	142.96

* Calculated specially for this book by the courtesy of the Hess Flume Company.

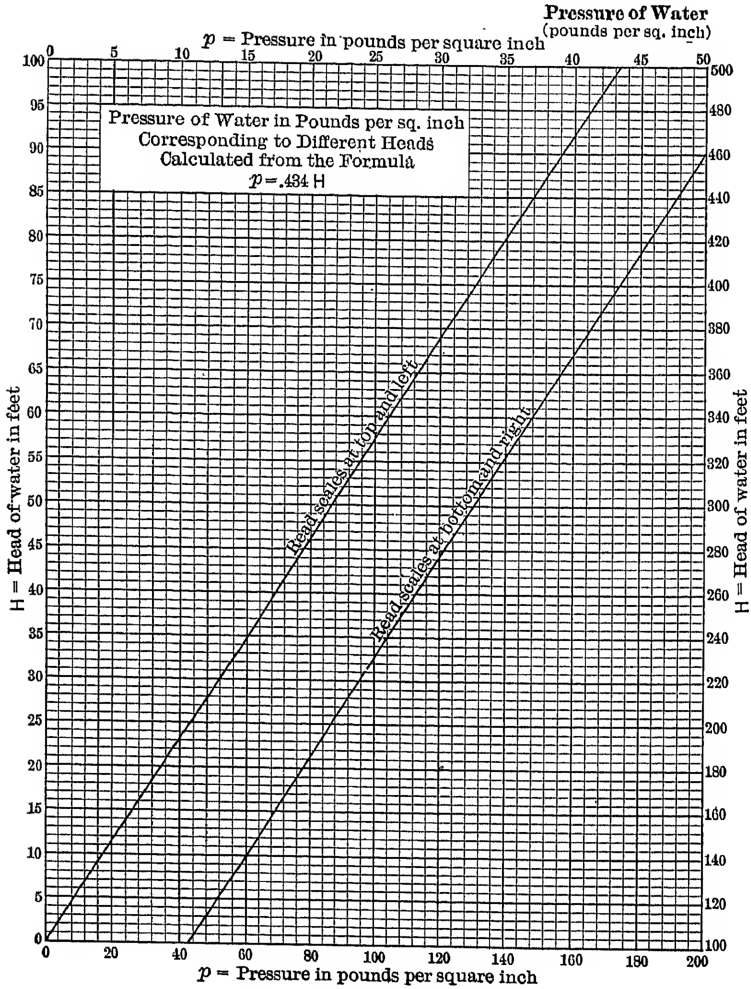
Pressure of Water
(pounds per sq. inch)
p = Pressure in pounds per square inch
Pressure of Water in Pounds per sq. inch
Corresponding to Different Heads
Calculated from the Formula
$p = .434\ H$
Read scales at top and left
Read scales at bottom and right
H = Head of water in feet
H = Head of water in feet
p = Pressure in pounds per square inch

FIG. 43.

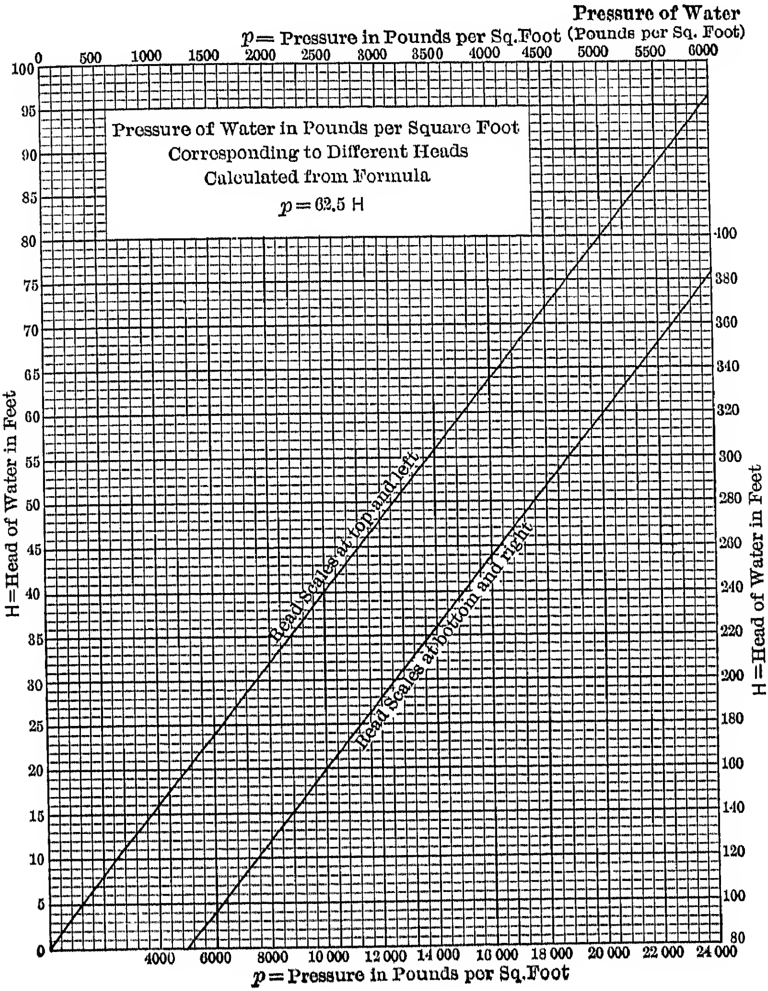
Pressure of Water
(Pounds per Sq. Foot)
p = Pressure in Pounds per Sq. Foot
0 500 1000 1500 2000 2500 3000 3500 4000 4500 5000 5500 6000
Pressure of Water in Pounds per Square Foot
Corresponding to Different Heads
Calculated from Formula
p = 62.5 H
H = Head of Water in Feet
100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0
400 380 360 340 320 300 280 260 240 220 200 180 160 140 120 100 80
Read Scales at top and left
Read Scales at bottom and right
4000 6000 8000 10 000 12 000 14 000 16 000 18 000 20 000 22 000 24 000
p = Pressure in Pounds per Sq. Foot

FIG. 44.

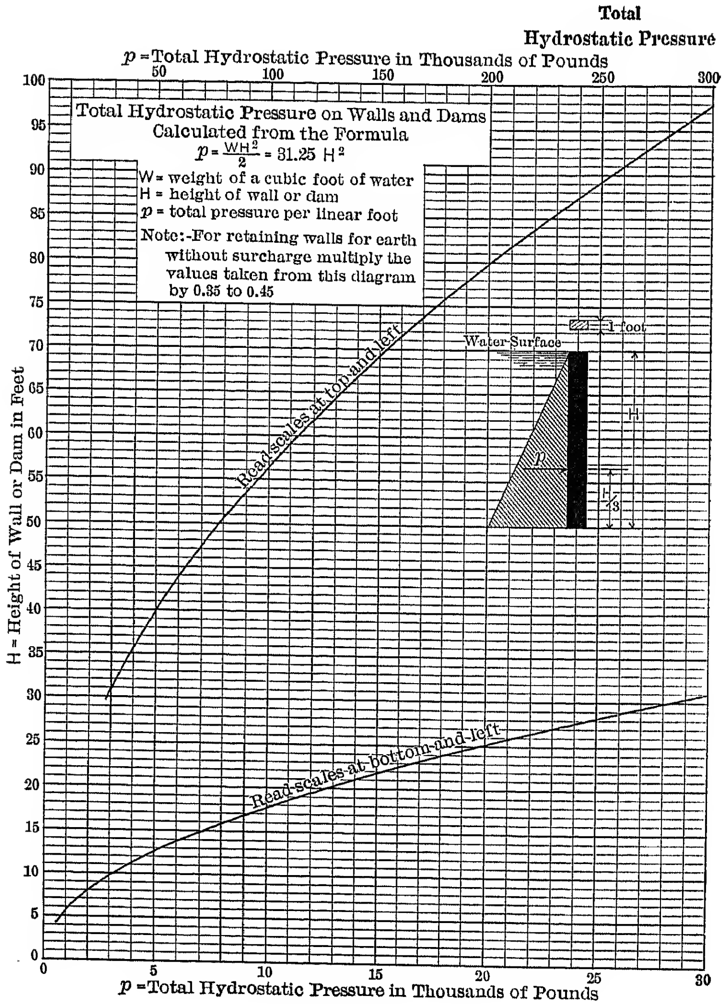
Total Hydrostatic Pressure
p = Total Hydrostatic Pressure in Thousands of Pounds
50 100 150 200 250 300
Total Hydrostatic Pressure on Walls and Dams
Calculated from the Formula
$p = \frac{WH^2}{2} = 31.25\ H^2$
W = weight of a cubic foot of water
H = height of wall or dam
p = total pressure per linear foot
Note:-For retaining walls for earth without surcharge multiply the values taken from this diagram by 0.35 to 0.45
1 foot
Water Surface
H
p
$\frac{H}{3}$
Read scales at top and left
Read scales at bottom and left
H = Height of Wall or Dam in Feet
100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0
0 5 10 15 20 25 30
p = Total Hydrostatic Pressure in Thousands of Pounds

FIG. 45.

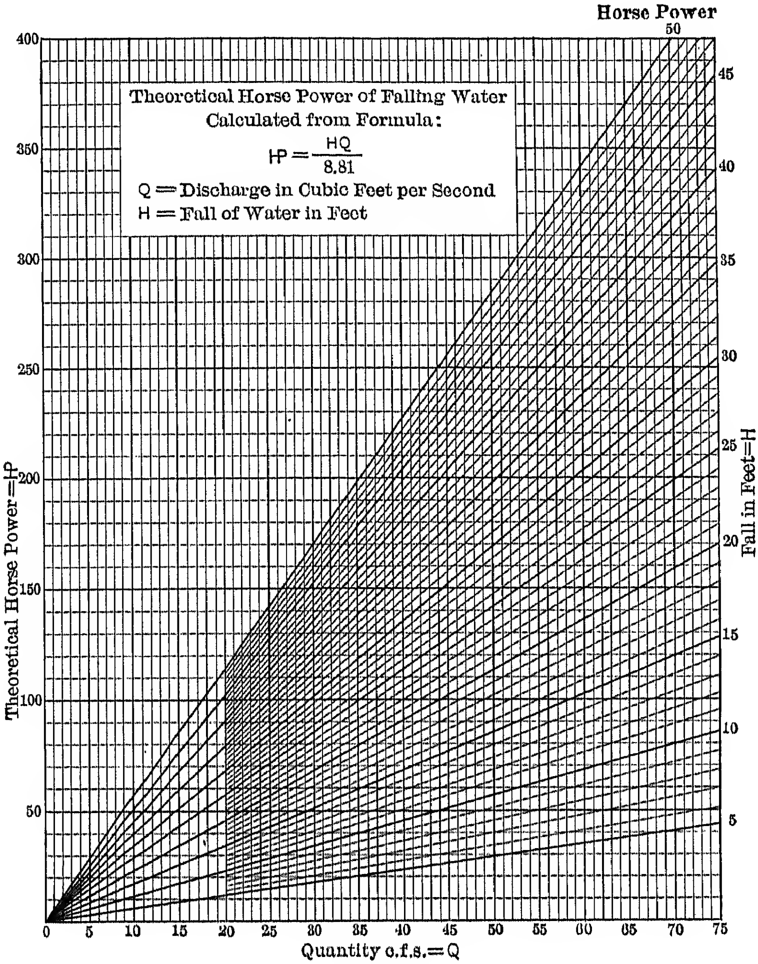
Horse Power
Theoretical Horse Power of Falling Water
Calculated from Formula:
HP = HQ / 8.81
Q = Discharge in Cubic Feet per Second
H = Fall of Water in Feet
Theoretical Horse Power = HP
Fall in Feet = H
Quantity c.f.s. = Q
400
350
300
250
200
150
100
50
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
45
40
35
30
25
20
15
10
5

FIG. 46.

Example 2.—What horse-power is produced by 155 c.f.s. dropping 30 feet? 155 c. f. s. is not represented on the diagram, but 15.5 c.f.s. is. We, therefore, enter at 15.5 c.f.s., and following through the same process as in example 1, read 52 horse-power. This is only one-tenth of the real horse-power, as the quantity used was only one-tenth of the real quantity. The real horse-power is, therefore, 520.

Example 3.—What horse-power is produced by 65 c. f. s. dropping 120 feet? 120 feet fall is not represented on the diagram, but 12 feet is. We, therefore, enter the diagram at $Q = 65$, and from the line representing a fall of 12 feet, read 89 horse-power. The real horse-power is, therefore, 890.

Example 4.—What horse-power is produced by 160 c.f.s. dropping 230 feet? In this case, both quantity and fall must be divided by 10 before entering the diagram, and the horse-power read must then be multiplied by 100. Entering the diagram with $Q = 16$ and $H = 23$ we read the horse-power to be 47. The real horse-power, therefore, is 4,700.

CHAPTER VI

MISCELLANEOUS TABLES AND DATA

CHAPTER VI

MISCELLANEOUS TABLES AND DATA

TABLE 50

AVERAGE WEIGHT, IN POUNDS PER CUBIC FOOT, OF VARIOUS SUBSTANCES

Substance	Weight
Clay, earth and mud:	
Clay	122–162
Earth, dry and loose	72–80
Earth, dry and shaken	82–92
Earth, dry and moderately rammed	90–100
Earth, slightly moist, loose	70–76
Earth, more moist, loose	66–68
Earth, more moist, shaken	75–90
Earth, more moist, moderately rammed	90–100
Earth, as soft flowing mud	104–112
Earth, as soft mud well pressed into a box	110–120
Mud, dry, close	80–110
Mud, wet, moderately pressed	110–130
Mud, wet, fluid	104–120
Masonry and its materials:	
Brick, best pressed	150
Brick, common hard	125
Brick, soft, inferior	100
Brickwork, pressed brick, fine joints	140
Brickwork, medium quality	125
Brickwork, coarse, inferior soft bricks	100
Cement, pulverized, loose	72–105
Cement, pressed	115
Cement, set	168–187
Concrete, 1:3:6	140
Gravel, loose	82–125
Gravel, rammed	90–145
Masonry of granite or stone of like weight:	
Well dressed	165
Well-scabbled rubble, 20 per cent mortar	154
Roughly scabbled rubble, 25 per cent to 35 per cent mortar	150
Well-scabbled dry rubble	138

Substance	Weight
Masonry and its materials—(*continued*):	
Roughly-scabbled dry rubble	125
Masonry of sandstone or stone of like weight weighs about seven-eighths of the above.	
Mortar, hardened	90–115
Sand, pure quartz, dry, loose	87–106
Sand, pure quartz, dry, slightly shaken	92–110
Sand, pure quartz, dry, rammed	100–120
Sand, natural, dry, loose	80–110
Sand, natural, dry, shaken	85–125
Sand, wet, voids full of water	118–128
Stone	135–195
Stone, quarried, loosely piled	80–110
Stone, broken, loose	77–112
Stone, broken, rammed	79–121
Metals and alloys	
Brass (copper and zinc)	487–524
Bronze (copper and tin)	524–537
Copper, cast	537–548
Copper, rolled	548–562
Iron and steel, cast	438–483
Average	450
Iron and steel, wrought	475–494
Average	480
Spelter or zinc	425–450
Tin, cast	450–470
Steel	490
Tin	459
Zinc	438
Mercury (32° F.)	849
Woods:	
See page 233	

TABLE 51

Convenient Equivalents

LENGTH

(See Table 53)

SURFACE

1 square inch = .006944 square foot = .0007716 square yard = .0000001594 acre = .0000000002491 square mile = 6.45163 square centimeters.

1 square foot = 144 square inches = $\frac{1}{9}$ square yard = .000022957 acre = .00000003587 square mile = .092903 square meters.

1 square yard = 1,296 square inches = 9 square feet = .0002066 acre = .0000003228 square mile = .83613 square meter.

1 acre = 6,272,640 square inches = 43,560 square feet = 4,840 square yards = .0015625 square mile = 208.71 feet square = .404687 hectare.

1 square mile = 4,014,489,600 square inches = 27,878,400 square feet = 3,097,600 square yards = 640 acres = 259 hectares.

1 square meter = 10,000 square centimeters = .0001 hectare = .000001 square kilometer = 1,550 square inches = 10.7639 square feet = 1.19598 square yards = .0002471 acre = .0000003861 square mile.

VOLUME

1 cubic inch = .004329 U. S. gallon = .0005787 cubic foot = 16.3872 cubic centimeters.

1 U. S. gallon = 231 cubic inches = .13368 cubic foot = .00000307 acre-foot = 3.78543 liters.

1 cubic foot = 1,728 cubic inches = 7.4805 U. S. gallons = .037037 cubic yard = .000022957 acre-foot = 28.317 liters.

1 cubic yard = 46,656 cubic inches = 27 cubic feet = .00061983 acre-foot = .76456 cubic meter.

1 acre-foot = 325,851 U. S. gallons = 43,560 cubic feet = 1,613⅓ cubic yards = 1,233.49 cubic meters.

1 cubic meter, stere or kiloliter = 1,000,000 cubic centimeters = 1,000 liters = 61,023.4 cubic inches = 264.17 U. S. gallons = 35.3145 cubic feet = 1.30794 cubic yards = .000810708 acre-foot.

HYDRAULICS

1 U. S. gallon of water weighs 8.34 pounds avoirdupois.

1 cubic foot of water weighs 62.4 pounds avoirdupois.

1 second-foot = 448.8 U. S. gallons per minute = 26,929.9 U. S. gallons per hour = 646,317 U. S. gallons per day.

= 60 cubic feet per minute = 3,600 cubic feet per hour = 86,400 cubic feet per day = 31,536,000 cubic feet per year = .000214 cubic miles per year.

= .9917 acre-inch per hour = 1.9835 acre-feet per day = 723.9669 acre-feet per year.

= 50 miner's inches in Idaho, Kansas, Nebraska, New Mexico, North Dakota, and South Dakota = 40 miner's inches in Arizona, California, Montana, and Oregon = 38.4 miner's inches in Colorado.

= .028317 cubic meters per second = 1.699 cubic meters per minute = 101.941 cubic meters per hour = 2,446.58 cubic meters per day.

1 cubic meter per minute = .5886 second-feet = 4.403 U. S. gallons per second = 1.1674 acre-feet per day.

1 million gallons per day = 1.55 second-feet = 3.07 acre-feet per day = 2.629 cubic meters per minute.

1 second-foot falling 8.81 feet = 1 horse-power.

1 second-foot falling 10 feet = 1.135 horse-power.

1 second-foot falling 11 feet = 1 horse-power, 80 per cent efficiency.

1 second-foot for 1 year will cover 1 square mile 1.131 feet or 13.572 inches deep.

1 inch deep on 1 square mile = 2,323,200 cubic feet = .0737 second-feet for 1 year.

MISCELLANEOUS

1 foot per second = .68 mile per hour = 1.097 kilometers per hour.

1 avoirdupois pound = 7,000 grains = .4536 kilogram.

1 kilogram = 1,000 grams = .001 tonne = 15,432 grains = 2.2046 pounds avoirdupois.

1 atmosphere = about $\begin{cases}\text{15 pounds per square inch.}\\ \text{1 ton per square foot.}\\ \text{1 kilogram per square centimeter.}\end{cases}$

Acceleration of gravity, g, = 32.16 feet per second per second.

1 horse-power = 5,694,120 foot-gallons per day = 550 foot-pounds per second = 33,000 foot-pounds per minute = 1,980,000 foot-pounds per hour = 76 kilogrammeters per second = 1.27 kilogrammeters per minute = 746 watts.

TABLE 52

Inches and Fractions Expressed in Decimals of a Foot

Inches	Fractions of Inches							
	0	1/8	1/4	3/8	1/2	5/8	3/4	7/8
0	.0000	.0104	.0208	.0313	.0417	.0521	.0625	.0729
1	.0833	.0937	.1041	.1146	.1250	.1354	.1458	.1562
2	.1667	.1771	.1875	.1980	.2084	.2188	.2292	.2396
3	.2500	.2604	.2708	.2813	.2917	.3021	.3125	.3229
4	.3333	.3437	.3541	.3646	.3750	.3854	.3958	.4062
5	.4167	.4271	.4375	.4480	.4584	.4688	.4792	.4896
6	.5000	.5104	.5208	.5313	.5417	.5521	.5625	.5729
7	.5833	.5937	.6041	.6146	.6250	.6354	.6458	.6562
8	.6667	.6771	.6875	.6980	.7084	.7188	.7292	.7396
9	.7500	.7604	.7708	.7813	.7919	.8021	.8125	.8229
10	.8333	.8437	.8541	.8646	.8750	.8854	.8958	.9062
11	.9167	.9271	.9375	.9480	.9584	.9688	.9792	.9896
12	1.0000	.....	.....	.....	.....	.....	.....	.....

TABLE 53

Comparison of Standard Linear Units (Approx. Values)

A	1 Millimeter Equals	1 Centimeter Equals	1 Inch Equals	1 Decimeter Equals	1 Foot Equals	1 Yard Equals	1 Meter Equals	1 Rod Equals	1 Chain Equals	1 Hectometer Equals	1 Furlong Equals	1 Kilometer Equals	1 Mile Equals	1 Knot Equals	A
Millimeters	1	10	25.4	100	304.80	914.40	1,000	5,029.2	20,116.8	100,000	201,168	1,000,000	1,609,347	1,855,037	Millimeters
Centimeters	1/10 .1	1	2.54	10	30.48	91.44	100	502.9	2,011.68	10,000	20,116.8	100,000	160,934	185,325	Centimeters
Inches	1/25 .03937	4/10 .3937	1	3.937	12	36	39.37	198	792	3,937	7,920	39,370	63,360	73,033	Inches
Decimeters	1/100 .01	1/10 .1	.254	1	3.048	9.144	10	50.29	201.16	1,000	2,011.7	10,000	16,093	18,532	Decimeters
Feet	.00328	1/30 .03280	1/12 .0833	1/3 .32808	1	3	3.2808 3′-33/8″	16.5	66	328.08	660	3,280.8	5,280	6,080.2	Feet
Yards	.00109	.01093	1/36 .0278	1/9 .10936	1/3 .3333	1	1.0936	5.5	22	109.36	220	1,093.6	1,760	2,026.7	Yards
Meters	1/1000 .001	1/100 .01	1/40 .02540	1/10 .1	3/10 .30480	9/10 .91440	1	5.0292	20.116	100	201.17	1,000	1,609.3	1,853.2	Meters
Rods	.00019	.00198	1/198 .00505	.01988	2/33 .06060	2/11 .18181	.19883	1	4	19.883	40	198.83	320	368.85	Rods
Chains	1/20000 .00005 –	1/2000 .00049	1/792 .00126	.00497	1/66 .01515	1/22 .04545	.04970	1/4 .25	1	4.9708	10	49.708	80	92.23	Chains
Hectometers	1/100000	1/10000	1/3937 .000254	1/1000	.00305	.00914	1/100	.05029	.20117	1	2.0117	10	16.093	18.53+	Hectometers
Furlongs	1/200000	1/20000	1/7920 .00012+	1/2000	1/660 .00151	1/220 .00454	.00497	1/40 .025	1/10	.49078	1	4.9708	8	9.223	Furlongs
Kilometers	....	1/100000	1/39370 .000025	1/10000	.00030	.00091	1/1000	.00503	.020117	1/10	.20117	1	1.6093+	1.853+	Kilometers
Miles	....	....	1/63360	....	1/5280	1/1760 .00056	.00062	1/320 .00312	1/80 .0125	.06213	1/8 .125	5/8 .62137	1	1.151+	Miles
Knots (U. S.)	....	....	1/73033	....	.00016	.00049	.00054	.00271	.01084	.05396	.10844	.5396+	App. 7/8 .8684+	1	Knots (U. S.)

Note.—At the point where any vertical column crosses any horizontal column will be found the value of the unit named at the head of the vertical column expressed in terms of the unit named under A opposite the horizontal column. Thus, 1 meter = 1.0936 yards. 1 foot = 0.3048 meter.

Table 57 is designed for use in stadia work and gives the difference in elevation corresponding to specified slant distances for vertical angles of 0° to 20°. The horizontal distances corresponding to the slant distances are also given for various vertical angles.

Example.—With the instrument at A a vertical angle of 3° 10′ is observed on a point B which is distant 350 feet by stadia reading; find the difference in elevation of A and B and the horizontal distance A B. Opposite 3° 10′ in the first column of the table, 16.5 is found under a distance of 300 and 22.1 under a distance of 400; and interpolation for a distance of 350 feet gives 19.3 feet for the difference in elevation of A and B. Interpolation for 350 between the values in the 300 and the 400 distance columns of the horizontal distance lines at 3° and 4° gives, respectively, 349.0 and 348.2; and an additional interpolation gives, for an angle of 3° 10′ and a slant distance of 350, a horizontal distance of 348.9. The horizontal distance of A B is, therefore, 348.9 feet.

Another method of making interpolations is as follows: Opposite 3° 10′ read as before, 16.5 feet vertical distance under the slant distance 300; then under the slant distance 500 and vertical angle 3° 10′ read 27.6 feet,—and divide this by 10 to get the vertical distance for 50 feet equals 2.76; add this to 16.5 and obtain 19.3 as the vertical distance for 350 feet. By a similar process the horizontal distances are found. If the slant distance were 355 feet the vertical distance would be $16.5 + \frac{27.6}{10} + \frac{27.6}{100} = 19.5$, and so on.

TABLE 54

TABLE FOR CONVERTING METERS AND

METERS CONVERTED INTO FEET

METERS	0	1	2	3	4	5
0		3-3 3/8; .2808	6-6 47/64; .5616	9-10 7/64; .8424	13-1 31/64; .1233	16-4 27/32; .4041
10	32-9 45/64; .8083	36-1 1/16; .0891	39-4 7/16; .3700	42-7 13/16; .6508	45-11 3/16; .9316	49-2 35/64; .2124
20	65-7 13/32; .6166	68-10 49/64; .8974	72-2 9/64; .1782	75-5 1/2; .4591	78-8 7/8; .74	82-0 1/4; .0207
30	98-5 3/32; .4249	101-8 15/32; .7057	104-11 27/32; .9865	108-3 13/64; .2673	111-6 37/64; .5482	114-9 61/64; .8290
40	131-2 51/64; .233	134-6 11/64; .5140	137-9 17/32; .7948	141-0 29/32; .0756	144-4 9/32; .3565	147-7 21/32; .6373
50	164-0 1/2; .041	167-3 7/8; .3223	170-7 15/64; .6031	173-10 39/64; .8839	177-1 63/64; .1648	180-5 11/32; .4456
60	196-10 3/16; .849	200-1 9/16; .1306	203-4 15/16; .4114	206-8 5/16; .6922	209-11 43/64; .9731	213-3 3/64; .2539
70	229-7 57/64; .6581	232-11 17/64; .9389	236-2 41/64; .2197	239-6″; .5006	242-9 3/8; .7814	246-0 3/4; .0622
80	262-5 19/32; .4664	265-8 31/32; .7472	269-0 11/32; .0280	272-3 45/64; .3088	275-7 5/64; .5897	278-10 29/64; .8705
90	295-3 19/64; .2747	298-6 43/64; .5555	301-10 1/32; .8363	305-1 13/32; .1171	308-4 25/32; .3980	311-8 9/64; .6788
100	328-1″; .083	331-4 23/64; .363	334-7 47/64; .6446	337-11 7/64; .9254	341-2 15/32; .2063	344-5 27/32; .4871
110	360-10 45/64; .8913	364-2 1/16; .1721	367-5 7/16; .4529	370-8 13/16; .7338	374-0 11/64; .0146	377-3 35/64; .2954
120	393-8 13/32; .7000	396-11 49/64; .9808	400-3 9/64; .2616	403-6 33/64; .5424	406-9 7/8; .8233	410-1 1/4; .1041
130	426-6 3/32; .5079	429-9 15/32; .7887	433-0 27/32; .0699	436-4 13/64; .3507	439-7 37/64; .6316	442-10 61/64; .9124
140	459-3 51/64; .3162	462-7 5/32; .5970	465-10 17/32; .8778	469-1 29/32; .1586	472-5 9/32; .4395	475-8 41/64; .7203
150	492-1 1/2; .1245	495-4 55/64; .4053	498-8 15/64; .6861	501-11 39/64; .9669	505-2 31/32; .2478	508-6 11/32; .5286
160	524-11 3/16; .9328	528-2 9/16; .2136	531-5 15/16; .4944	534-9 19/64; .7753	538-0 43/64; .0561	541-4 3/64; .3369
170	557-8 57/64; .7411	561-0 17/64; .0219	564-3 5/8; .3027	567-7″; .5835	570-10 3/8; .8644	574-1 3/4; .1452
180	590-6 19/32; .5494	593-9 31/32; .8302	597-1 21/64; .1110	600-4 45/64; .3918	603-8 5/64; .6727	606-11 7/16; .9535
190	623-4 19/64; .3577	626-7 21/32; .6385	629-11 1/32; .9193	633-2 13/32; .2002	636-5 49/64; .4810	639-9 9/64; .7618
200	656-1 63/64; .166	659-5 23/64; .4468	662-8 47/64; .7276	666-0 7/64; .0085	669-3 15/32; .2893	672-6 27/32; .5701
210	688-11 11/16; .9743	692-3 1/16; .2551	695-6 7/16; .5359	698-9 51/64; .8168	702-1 11/64; .0976	705-4 35/64; .3784
220	721-9 25/64; .7826	725-0 49/64; .0634	728-4 1/8; .3442	731-7 1/2; .6251	734-10 7/8; .9059	738-2 15/64; .1867
230	754-7 3/32; .5909	757-10 29/64; .8717	761-1 53/64; .1525	764-5 13/64; .4334	767-8 37/64; .7142	770-11 15/16; .9950
240	787-4 51/64; .3992	790-8 5/32; .6800	793-11 17/32; .9608	797-2 29/32; .2417	800-6 17/64; .5225	803-9 41/64; .8033
250	820-2 1/2; .2083	823-5 55/64; .4883	826-9 15/64; .7691	830-0 19/32; .0499	833-3 31/32; .3308	836-7 11/32; .6116
260	853-0 13/64; .016	856-3 9/16; .2966	859-6 59/64; .5774	862-10 19/64; .8583	866-1 43/64; .1391	869-5 1/32; .4199
270	885-9 29/32; .824	889-1 17/64; .1049	892-4 5/8; .3857	895-8″; .6666	898-11 3/8; .9474	902-2 47/64; .2282
280	918-7 19/32; .6333	921-10 61/64; .9132	925-2 21/64; .1940	928-5 45/64; .4749	931-9 1/16; .7557	935-0 7/16; .0365
290	951-5 19/64; .4416	954-8 21/32; .7215	958-0 1/32; .0023	961-3 25/64; .2832	964-6 49/64; .5640	967-10 9/64; .8448
300	984-3″; .250	987-6 23/64; .5298	990-9 47/64; .8106	994-1 3/32; .0915	997-4 15/32; .3723	1000-7 27/32; .6531

NOTE: Values of converted even meters are expressed
of 1 foot. For example 74 meters = 242′-9⅜″ or 242.781′.
table. For example .3 meter = 11.811 inches = .984 ft. =
To convert 147.678 meters into feet: 147.000 m = 482.282 ft.

.6 " =	1.986 "
.07 " =	.229 "
.008 " =	.026 "
147.678 m =	484.505 "

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TABLE 54 (*Concluded*)

MILLIMETERS INTO FEET AND INCHES

WITH INCHES TO NEAREST 64TH

6	7	8	9	METERS
19-8 7/32 .6849	22-11 19/32 .9658	26-2 61/64 .2466	29-6 21/64 .5274	0
52-5 59/64 .4932	55-9 19/64 .7741	59-0 21/32 .0549	62-4 1/32 .3357	10
85-3 5/8 .3016	88-6 63/64 .5824	91-10 23/64 .8632	95-1 47/64 .1440	20
118-1 5/16 .1098	121-4 11/16 .3907	124-8 1/16 .6715	127-11 27/64 .9523	30
150-11 1/64 .9181	154-2 25/64 .1990	157-5 3/4 .4798	160-9 1/8 .7606	40
183-8 23/32 .7264	187-0 3/32 .0073	190-3 29/64 .2881	193-6 53/64 .5689	50
216-6 27/64 .5347	219-9 25/32 .8156	223-1 5/32 .0964	226-4 17/32 .3772	60
249-4 7/64 .3430	252-7 31/64 .6239	255-10 55/64 .9047	259-2 7/32 .1855	70
282-1 13/16 .1513	285-5 3/16 .4322	288-8 9/16 .7130	291-11 59/64 .9938	80
314-11 33/64 .9596	318-2 57/64 .2405	321-6 1/4 .5213	324-9 5/8 .8021	90
347-9 7/32 .7679	351-0 37/64 .0488	354-3 61/64 .3298	357-7 21/64 .6104	100
380-6 59/64 .5762	383-10 9/32 .8571	387-1 21/32 .1379	390-5 1/32 .4187	110
413-4 5/8 .3849	416-7 63/64 .6658	419-11 23/64 .9466	423-2 47/64 .2274	120
446-2 5/16 .1932	449-5 11/16 .4741	452-9 1/16 .7549	456-0 27/64 .0357	130
479-0 1/64 .0011	482-3 25/64 .2820	485-6 3/4 .5628	488-10 1/8 .8436	140
511-9 23/32 .8094	515-1 5/64 .0903	518-4 29/64 .3711	521-7 53/64 .6519	150
544-7 13/32 .6177	547-10 25/32 .8986	551-2 5/32 .1794	554-5 33/64 .4602	160
577-5 7/64 .4260	580-8 31/64 .7069	583-11 55/64 .9877	587-3 7/32 .2885	170
610-2 13/16 .2343	613-6 3/16 .5152	616-9 35/64 .7960	620-0 59/64 .0768	180
643-0 33/64 .0426	646-3 7/8 .3235	649-7 1/4 .6043	652-10 5/8 .8851	190
675-10 13/64 .8509	679-1 37/64 .1318	682-4 61/64 .4126	685-8 21/64 .6934	200
708-7 29/32 .6592	711-11 9/32 .9401	715-2 21/32 .2209	718-6 1/64 .5017	210
741-5 55/64 .4876	744-8 63/64 .7484	748-0 11/32 .0292	751-3 23/32 .3101	220
774-3 5/16 .2759	777-6 11/16 .5567	780-10 3/64 .8375	784-1 27/64 .1183	230
807-1 1/64 .0842	810-4 3/8 .3650	813-7 3/4 .6458	816-11 1/8 .9266	240
839-10 45/64 .8925	843-2 5/64 .1733	846-5 29/64 .4541	849-8 13/16 .7349	250
872-8 13/32 .7008	875-11 25/32 .9816	879-3 5/32 .2624	882-6 33/64 .5433	260
905-6 7/64 .5091	908-9 31/64 .7899	912-0 27/32 .0707	915-4 7/32 .3516	270
938-3 13/16 .3174	941-7 11/64 .5982	944-10 35/64 .8790	948-1 59/64 .1599	280
971-1 1/2 .1256	974-4 7/8 .4065	977-8 1/4 .6873	980-11 5/8 .9682	290
1003-11 13/64 .9339	1007-2 37/64 .2148	1010-5 61/64 .4956	1013-9 5/16 .7765	300

10THS ETC. OF 1 METER CONVERTED INTO

D.C.M.	A INCHES	B FEET	C FEET AND INCHES TO NEAREST 1/64		D.C.M.	
.1	3.937	.3281	0'-3 15/16"		1	HUNDREDS OF MM. DECIMETERS
.2	7.874	.6561	0'-7 7/8"		2	
.3	11.811	.984	0'-11 13/16"+		3	
.4	15.748	1.312	1'-3 3/4" +		4	
.5	19.685	1.640^{4}	1'-7 11/16"+		5	
.6	23.622	1.968^{4}	1'-11 5/8"+		6	
.7	27.559	2.296^{5}	2'-3 9/16" +		7	
.8	31.496	2.624^{6}	2'-7 1/2" −		8	
.9	35.433	2.952^{7}	2'-11 7/16"+		9	
			AP'X	NEAREST 64TH		
.01	.393	.032	3/8"	0 25/64"−	1	TENS OF MM. CENTIMETERS
.02	.787	.065	3/4"	0 25/32"+	2	
.03	1.181	.098		1 3/16"+	3	
.04	1.574	.131	1 9/16"	1 37/64"+	4	
.05	1.968	.164	2"	1 31/32"+	5	
.06	2.362	.196	2 3/8"	2 23/64"+	6	
.07	2.756	.229		2 3/4"+	7	
.08	3.149	.262		3 5/32"+	8	
.09	3.543	.295	3 9/16"	3 35/64"+	9	
			AP'X	NEAREST		
.001	.039	.003	1/25"	5/128"−	1	MILLIMETERS
.002	.078	.006	1/13"	5/64"−	2	
.003	.118	.009	1/8"	15/128"+	3	
.004	.157	.013	1/6"	5/32"	4	
.005	.196	.016	1/5"	25/128"	5	
.006	.236	.019	1/4"	15/64"	6	
.007	.275	.023	1/4"	9/32"	7	
.008	.315	.026	1/3"	5/16"	8	
.009	.354	.029	1/3"	23/64"	9	

in feet and inches to nearest 64th, and also as feet and decimal
Fractions of meter are read from the right hand portion of the
0'-11 13/16". .07 meter = 2.756 in = .229 ft. = 0'-2 3/4"

To convert same number to feet and inches: 147.000 m = 482'-3 25/64"

147.000 m	= 482'-3 25/64"
.6 "	= 1-11 5/8
.07 "	= 0-2 3/4
.008 "	= 0-0 5/16
147.678 m	= 484'-6 5/64"

TABLE 55

TABLES FOR CONVERTING FEET AND INCHES INTO METERS AND MILLIMETERS. Meter is taken = 39.370432 inches

Feet Converted into Meters and Decimals (Millimeters) [1]

Feet	0	1	2	3	4	5	6	7	8	9
0	......	.304	.609	.914	1.219	1.524	1.828	2.133	2.438	2.743
10	3.048	3.352	3.657	3.962	4.267	4.572	4.876	5.181	5.486	5.791
20	6.096	6.400	6.705	7.010	7.315	7.620	7.924	8.230	8.534	8.840
30	9.143	9.448	9.753	10.058	10.363	10.667	10.972	11.277	11.582	11.887
40	12.191	12.496	12.801	13.106	13.411	13.715	14.020	14.325	14.630	14.935
50	15.240	15.544	15.850	16.154	16.459	16.763	17.068	17.373	17.678	17.983
60	18.287	18.592	18.897	19.202	19.506	19.811	20.116	20.421	20.726	21.030
70	21.335	21.640	21.945	22.250	22.554	22.860	23.164	23.470	23.774	24.078
80	24.383	24.688	24.993	25.297	25.602	25.907	26.212	26.517	26.822	27.126
90	27.431	27.736	28.041	28.346	28.650	28.955	29.260	29.565	29.870	30.174

[1] Approximately only. Example: 33 feet = 10.058 meters.

EXAMPLE.—To convert 127 feet 8½ inches to meters:

From Table 55....100 ft.	= 30.48	meters
From Table 55.... 27 ft.	= 8.23	"
From Table 55 A.. 8½ in.	= .215	"
127 ft. 8½ in.	= 38.925	meters

or

127 ft.	=	(63 ft. 6 in.) × 2
63 ft.	=	19.202 meters
63 ft.	=	19.202 "
1 ft.	=	.304 meter
8½ in.	=	.215 "
		38.923 meters

EXAMPLE.—To convert 13 feet 6¾ inches into meters:

From Table 55......13 ft.	= 3.962	meters
From Table 55 A....6¾ ins.	= .171	meters
13 ft. 6¾ in.	= 4.133	meters

TABLE 55 A

Inches and Sixteenths Converted into Millimeters and Decimals [1]

Inches	0	1	2	3	4	5	6	7	8	9	10	11
..	......	25.400	50.799	76.199	101.60	127.00	152.40	177.80	203.20	228.60	254.00	279.39
1/16	1.587	26.987	52.387	77.786	103.19	128.59	153.98	179.38	204.78	230.18	255.58	280.98
1/8	3.175	28.574	53.974	79.374	104.77	130.17	155.57	180.97	206.37	231.77	257.17	282.57
3/16	4.762	30.162	55.561	80.961	106.36	131.76	157.16	182.56	207.96	233.36	258.76	284.16
1/4	6.350	31.749	57.149	82.549	107.95	133.35	158.75	184.15	209.55	234.95	260.35	285.74
5/16	7.937	33.337	58.736	84.136	109.54	134.94	160.33	185.73	211.13	236.53	261.93	287.33
3/8	9.524	34.924	60.324	85.723	111.12	136.52	161.92	187.32	212.72	238.12	263.52	288.92
7/16	11.112	36.512	61.911	87.311	112.71	138.11	163.51	188.91	214.31	239.71	265.11	290.51
1/2	12.700	38.099	63.499	88.898	114.30	139.70	165.10	190.50	215.90	241.30	266.70	292.09
9/16	14.287	39.687	65.086	90.486	115.89	141.28	166.68	192.08	217.48	242.88	268.28	293.68
5/8	15.875	41.274	66.674	92.073	117.47	142.87	168.27	193.67	219.07	244.47	269.87	295.27
11/16	17.462	42.862	68.261	93.661	119.06	144.46	169.86	195.26	220.66	246.06	271.46	296.86
3/4	19.050	44.449	69.849	95.248	120.65	146.05	171.45	196.85	222.25	247.65	273.05	298.44
13/16	20.637	46.037	71.436	96.836	122.24	147.63	173.03	198.43	223.83	249.23	274.63	300.03
7/8	22.225	47.624	73.024	98.423	123.82	149.22	174.62	200.02	225.42	250.82	276.22	301.62
15/16	23.813	49.212	74.611	100.01	125.41	150.81	176.21	201.61	227.01	252.41	227.81	303.21

[1] Approximately only. Example: 4 5/16 inches = 109.54 millimeters = .10954 meter.

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TABLE 56

CORRECTION IN FEET FOR CURVATURE AND REFRACTION

($h = 0.574\ D^2$)

D = Distance in miles

Distance, in Miles	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
1	.6	.7	.8	1.0	1.1	1.3	1.5	1.7	1.9	2.1
2	2.3	2.5	2.8	3.0	3.3	3.6	3.9	4.2	4.5	4.8
3	5.2	5.5	5.9	6.2	6.6	7.0	7.4	7.8	8.3	8.7
4	9.2	9.6	10.1	10.6	11.1	11.6	12.1	12.7	13.2	13.8
5	14.3	14.9	15.5	16.1	16.7	17.3	18.0	18.6	19.3	20.0
6	20.7	21.4	22.1	22.8	23.5	24.2	25.0	25.7	26.5	27.3
7	28.1	28.9	29.8	30.6	31.4	32.3	33.2	34.1	35.0	35.9
8	36.7	37.6	38.6	39.5	40.4	41.4	42.4	43.4	44.4	45.5
9	46.5	47.5	48.6	49.7	50.7	51.8	52.9	54.0	55.1	56.3
10	57.4	58.6	59.7	60.9	62.1	63.3	64.5	65.7	67.0	68.2
11	69.5	70.7	71.9	73.2	74.5	75.8	77.1	78.5	79.8	81.2
12	82.7	84.0	85.4	86.8	88.3	89.7	91.1	92.6	94.0	95.5
13	97.0	98.5	100.0	101.5	103.1	104.6	106.2	107.7	109.3	110.9
14	112.5	114.1	115.7	117.4	119.0	120.7	122.4	124.0	125.7	127.4
15	129.1	130.9	132.6	134.3	136.1	137.9	139.7	141.5	143.3	145.1
16	146.9	148.7	150.6	152.5	154.4	156.3	158.2	160.1	162.0	163.9
17	165.8	167.8	169.8	171.7	173.7	175.7	177.7	179.7	181.8	183.8
18	185.9	188.0	190.1	192.2	194.3	196.4	198.5	200.7	202.8	205.0
19	207.1	209.3	211.5	213.7	216.0	218.2	220.4	222.7	224.9	227.2
20	229.5	231.8	234.2	236.5	238.8	241.2	243.5	245.9	248.3	250.7
21	253.1	255.5	257.9	260.4	262.8	265.3	267.7	270.2	272.7	275.2
22	277.7	280.3	282.8	285.4	288.0	290.5	293.1	295.7	298.3	301.0
23	303.6	306.2	308.9	311.5	314.2	316.9	319.6	322.3	325.0	327.8
24	330.5	333.3	336.1	338.9	341.7	344.5	347.3	350.1	352.9	355.8
25	358.6	361.5	364.4	367.3	370.2	373.1	376.0	379.0	381.9	384.9
26	387.9	390.9	393.9	396.9	400.0	403.0	406.0	409.1	412.2	415.3
27	418.3	421.4	424.5	427.7	430.8	434.0	437.1	440.3	443.5	446.7
28	449.9	453.1	456.3	459.6	462.8	466.1	469.4	472.7	476.0	479.3
29	482.6	485.9	489.3	492.6	496.0	499.4	502.8	506.2	509.6	513.0
30	516.5	519.9	523.4	526.8	530.3	533.8	537.3	540.8	544.4	547.9
31	551.5	555.0	558.6	562.2	565.8	509.4	573.0	576.7	580.3	584.0
32	587.6	591.3	595.0	598.7	602.4	606.1	609.9	613.6	617.3	621.1
33	624.9	628.7	532.5	636.3	640.2	644.0	647.9	651.7	655.6	659.5
34	663.4	667.3	671.2	675.1	679.1	683.0	687.0	690.9	694.9	698.9
35	702.9	707.0	711.0	715.1	719.1	723.2	727.3	731.4	735.5	739.6
36	743.7	747.8	752.0	756.1	760.3	764.5	768.7	772.9	777.1	781.3
37	785.6	789.8	794.1	798.4	802.6	806.9	811.3	815.6	819.9	824.2
38	828.6	833.0	837.4	841.8	846.2	850.6	855.0	859.4	863.9	868.3
39	872.8	877.3	881.8	886.3	890.8	895.3	899.9	904.4	909.0	913.5
40	918.1	922.7	927.3	931.9	936.6	941.2	945.9	950.5	955.2	959.9

TABLE 57
Stadia Table

Slant Distance	100	200	300	400	500	600	700	800	900
0° 2′	0.06	0.1	0.2	0.2	0.3	0.3	0.4	0.5	0.5
4	0.12	0.2	0.3	0.5	0.6	0.7	0.8	0.9	1.0
6	0.17	0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.6
8	0.23	0.5	0.7	0.9	1.2	1.4	1.6	1.9	2.1
10	0.29	0.6	0.9	1.2	1.5	1.7	2.0	2.3	2.6
12	0.35	0.7	1.0	1.4	1.7	2.1	2.4	2.8	3.1
14	0.41	0.8	1.2	1.6	2.0	2.4	2.8	3.3	3.7
16	0.47	0.9	1.4	1.9	2.3	2.8	3.3	3.7	4.2
18	0.52	1.0	1.6	2.1	2.6	3.1	3.7	4.2	4.7
20	0.58	1.2	1.7	2.3	2.9	3.5	4.1	4.6	5.2
22	0.64	1.3	1.9	2.6	3.2	3.8	4.5	5.1	5.8
24	0.70	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3
26	0.76	1.5	2.3	3.0	3.8	4.5	5.3	6.0	6.3
28	0.81	1.6	2.4	3.2	4.1	4.9	5.7	6.5	7.3
30	0.87	1.7	2.6	3.5	4.4	5.2	6.1	7.0	7.8
32	0.93	1.9	2.8	3.7	4.6	5.6	6.5	7.4	8.4
34	0.99	2.0	3.0	3.9	4.9	5.9	6.9	7.9	8.9
36	1.05	2.1	3.1	4.2	5.2	6.3	7.3	8.4	9.4
38	1.11	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9
40	1.16	2.3	3.5	4.6	5.8	7.0	8.1	9.3	10.5
42	1.22	2.4	3.7	4.9	6.1	7.3	8.5	9.8	11.0
44	1.28	2.6	3.8	5.1	6.4	7.7	9.0	10.2	11.5
46	1.34	2.7	4.0	5.3	6.7	8.0	9.4	10.7	12.0
48	1.40	2.8	4.2	5.6	7.0	8.4	9.8	11.2	12.5
50	1.45	2.9	4.4	5.8	7.2	8.7	10.2	11.6	13.1
52	1.51	3.0	4.5	6.0	7.5	9.1	10.6	12.1	13.6
54	1.57	3.1	4.7	6.3	7.8	9.4	11.0	12.6	14.1
56	1.63	3.3	4.9	6.5	8.1	9.8	11.4	13.0	14.6
58	1.69	3.4	5.0	6.7	8.4	10.1	11.8	13.5	15.2
60	1.74	3.5	5.2	7.0	8.7	10.5	12.2	14.0	15.7
1° 2′	1.80	3.6	5.4	7.2	9.0	10.8	12.6	14.4	16.2
4	1.86	3.7	5.6	7.4	9.3	11.2	13.0	14.9	16.7
6	1.92	3.8	5.8	7.7	9.6	11.5	13.4	15.4	17.3
8	1.98	4.0	5.9	7.9	9.9	11.9	13.8	15.8	17.8
10	2.03	4.1	6.1	8.1	10.2	12.2	14.2	16.3	18.3
12	2.09	4.2	6.3	8.4	10.5	12.6	14.7	16.7	18.8
14	2.15	4.3	6.5	8.6	10.8	12.9	15.1	17.2	19.4
16	2.21	4.4	6.6	8.8	11.0	13.3	15.5	17.7	19.9
18	2.27	4.5	6.8	9.1	11.3	13.6	15.9	18.1	20.4
20	2.33	4.7	7.0	9.3	11.6	14.0	16.3	18.6	20.9
22	2.38	4.8	7.2	9.5	11.9	14.3	16.7	19.1	21.5
24	2.44	4.9	7.3	9.8	12.2	14.7	17.1	19.5	22.0
26	2.50	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5
28	2.56	5.1	7.7	10.2	12.8	15.3	17.9	20.5	23.0
30	2.62	5.2	7.8	10.5	13.1	15.7	18.3	20.9	23.5
32	2.67	5.3	8.0	10.7	13.4	16.0	18.7	21.4	24.1
34	2.73	5.5	8.2	10.9	13.7	16.4	19.1	21.9	24.6
36	2.79	5.6	8.4	11.2	14.0	16.7	19.5	22.3	25.1
38	2.85	5.7	8.5	11.4	14.2	17.1	19.9	22.8	25.6
40	2.91	5.8	8.7	11.6	14.5	17.4	20.3	23.3	26.2
42	2.97	5.9	8.9	11.9	14.8	17.8	20.8	23.7	26.7
44	3.02	6.0	9.1	12.1	15.1	18.1	21.2	24.2	27.2
46	3.08	6.2	9.2	12.3	15.4	18.5	21.6	24.6	27.7
48	3.14	6.3	9.4	12.6	15.7	18.8	22.0	25.1	28.3
50	3.20	6.4	9.6	12.8	16.0	19.2	22.4	25.6	28.8
52	3.26	6.5	9.8	13.0	16.3	19.5	22.8	26.0	29.3
54	3.31	6.6	9.9	13.2	16.6	19.9	23.2	26.5	29.8
56	3.37	6.7	10.1	13.5	16.9	20.2	23.6	27.0	30.3
58	3.43	6.9	10.3	13.7	17.1	20.6	24.0	27.4	30.9
60	3.49	7.0	10.5	14.0	17.4	20.9	24.4	27.9	31.4
Horizontal dist.	**99.9**	**199.8**	**299.6**	**399.5**	**499.4**	**599.3**	**699.2**	**799.0**	**898.9**

TABLE 57 (*Continued*)

STADIA TABLE

Slant Distance		100	200	300	400	500	600	700	800	900
2°	2′	3.55	7.1	10.6	14.2	17.7	21.3	24.8	28.4	31.9
	4	3.60	7.2	10.8	14.4	18.0	21.6	25.2	28.8	32.4
	6	3.66	7.3	11.0	14.6	18.3	22.0	25.6	29.3	33.0
	8	3.72	7.4	11.2	14.9	18.6	22.3	26.0	29.8	33.5
	10	3.78	7.6	11.3	15.1	18.9	22.7	26.4	30.2	34.0
	12	3.84	7.7	11.5	15.3	19.2	23.0	26.9	30.7	34.5
	14	3.90	7.8	11.7	15.6	19.5	23.4	27.3	31.2	35.1
	16	3.95	7.9	11.9	15.8	19.8	23.7	27.7	31.6	35.6
	18	4.01	8.0	12.0	16.0	20.0	24.1	28.1	32.1	36.1
	20	4.07	8.1	12.2	16.3	20.3	24.4	28.5	32.5	36.6
	22	4.13	8.3	12.4	16.5	20.6	24.8	28.9	33.0	37.1
	24	4.18	8.4	12.6	16.7	20.9	25.1	29.3	33.5	37.7
	26	4.24	8.5	12.7	17.0	21.2	25.5	29.7	33.9	38.2
	28	4.30	8.6	12.9	17.2	21.5	25.8	30.1	34.4	38.7
	30	4.36	8.7	13.1	17.4	21.8	26.1	30.5	34.9	39.2
	32	4.42	8.8	13.2	17.7	22.1	26.5	30.9	35.3	39.7
	34	4.47	8.9	13.4	17.9	22.4	26.8	31.3	35.8	40.3
	36	4.53	9.1	13.6	18.1	22.7	27.2	31.7	36.3	40.8
	38	4.59	9.2	13.8	18.4	23.0	27.5	32.1	36.7	41.3
	40	4.65	9.3	13.9	18.6	23.2	27.9	32.5	37.2	41.8
	42	4.71	9.4	14.1	18.8	23.5	28.2	32.9	37.6	42.4
	44	4.76	9.5	14.3	19.1	23.8	28.6	33.3	38.1	42.9
	46	4.82	9.6	14.5	19.3	24.1	28.9	33.8	38.6	43.4
	48	4.88	9.8	14.6	19.5	24.4	29.3	34.2	39.0	43.9
	50	4.94	9.9	14.8	19.8	24.7	29.6	34.6	39.5	44.4
	52	5.00	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0
	54	5.05	10.1	15.2	20.2	25.3	30.3	35.4	40.4	45.5
	56	5.11	10.2	15.3	20.4	25.6	30.7	35.8	40.9	46.0
	58	5.17	10.3	15.5	20.7	25.8	31.0	36.2	41.4	46.5
	60	5.23	10.5	15.7	20.9	26.1	31.4	36.6	41.8	47.1
Horizontal dist.		**99.7**	**199.5**	**299.2**	**398.9**	**498.7**	**598.4**	**698.1**	**797.8**	**897.5**
3°	2′	5.28	10.6	15.9	21.1	26.4	31.7	37.0	42.3	47.6
	4	5.34	10.7	16.0	21.4	26.7	32.1	37.4	42.7	48.1
	6	5.40	10.8	16.2	21.6	27.0	32.4	37.8	43.2	48.6
	8	5.46	10.9	16.4	21.8	27.3	32.7	38.2	43.7	49.1
	10	5.52	11.0	16.5	22.1	27.6	33.1	38.6	44.1	49.6
	12	5.57	11.1	16.7	22.3	27.9	33.4	39.0	44.6	50.2
	14	5.63	11.3	16.9	22.5	28.2	33.8	39.4	45.0	50.7
	16	5.69	11.4	17.1	22.8	28.4	34.1	39.8	45.5	51.2
	18	5.75	11.5	17.2	23.0	28.7	34.5	40.2	46.0	51.7
	20	5.80	11.6	17.4	23.2	29.0	34.8	40.6	46.4	52.2
	22	5.86	11.7	17.6	23.4	29.3	35.1	41.0	46.9	52.8
	24	5.92	11.8	17.8	23.7	29.6	35.5	41.4	47.4	53.3
	26	5.98	12.0	17.9	23.9	29.9	35.9	41.8	47.8	53.8
	28	6.04	12.1	18.1	24.1	30.2	36.2	42.2	48.3	54.3
	30	6.09	12.2	18.3	24.4	30.5	36.6	42.6	48.7	54.8
	32	6.15	12.3	18.4	24.6	30.8	36.9	43.0	49.2	55.4
	34	6.21	12.4	18.6	24.8	31.0	37.3	43.5	49.7	55.9
	36	6.27	12.5	18.8	25.1	31.3	37.6	43.9	50.1	56.4
	38	6.32	12.6	19.0	25.3	31.6	37.9	44.3	50.6	56.9
	40	6.38	12.8	19.1	25.5	31.9	38.3	44.7	51.1	57.4
	42	6.44	12.9	19.3	25.8	32.2	38.6	45.1	51.5	58.0
	44	6.50	13.0	19.5	26.0	32.5	39.0	45.5	52.0	58.5
	46	6.55	13.1	19.7	26.2	32.8	39.3	45.9	52.4	59.0
	48	6.61	13.2	19.8	26.4	33.1	39.7	46.3	52.9	59.5
	50	6.67	13.3	20.0	26.7	33.4	40.0	46.7	53.4	60.0
	52	6.73	13.5	20.2	26.9	33.6	40.4	47.1	53.8	60.6
	54	6.78	13.6	20.4	27.1	33.9	40.7	47.5	54.3	61.1
	56	6.84	13.7	20.5	27.4	34.2	41.1	47.9	54.7	61.6
	58	6.90	13.8	20.7	27.6	34.5	41.4	48.3	55.2	62.1
	60	6.96	13.9	20.9	27.8	34.8	41.7	48.7	55.7	62.6
Horizontal dist.		**99.5**	**199 0**	**298.5**	**398.0**	**497.6**	**597.1**	**696.6**	**796.1**	**895.6**

TABLE 57 (*Continued*)

STADIA TABLE

Slant Distance	100	200	300	400	500	600	700	800	900
4° 2′	7.02	14.0	21.0	28.1	35.1	42.1	49.1	56.1	63.1
4	7.07	14.1	21.2	28.3	35.4	42.4	49.5	56.6	63.7
6	7.13	14.3	21.4	28.5	35.7	42.8	49.9	57.0	64.2
8	7.19	14.4	21.6	28.8	35.9	43.1	50.3	57.5	64.7
10	7.25	14.5	21.7	29.0	36.2	43.5	50.7	58.0	65.2
12	7.30	14.6	21.9	29.2	36.5	43.8	51.1	58.4	65.7
14	7.36	14.7	22.1	29.4	36.8	44.2	51.5	58.9	66.2
16	7.42	14.8	22.3	29.7	37.1	44.5	51.9	59.3	66.8
18	7.48	15.0	22.4	29.9	37.4	44.9	52.3	59.8	67.3
20	7.53	15.1	22.6	30.2	37.7	45.2	52.7	60.3	67.8
22	7.59	15.2	22.8	30.4	38.0	45.5	53.1	60.7	68.3
24	7.65	15.3	22.9	30.6	38.2	45.9	53.5	61.2	68.8
26	7.71	15.4	23.1	30.8	38.5	46.2	53.9	61.6	69.3
28	7.76	15.5	23.3	31.1	38.8	46.6	54.3	62.1	69.9
30	7.82	15.6	23.5	31.3	39.1	46.9	54.7	62.6	70.4
32	7.88	15.8	23.6	31.5	39.4	47.3	55.1	63.0	70.9
34	7.94	15.9	23.8	31.7	39.7	47.6	55.5	63.5	71.4
36	7.99	16.0	24.0	32.0	40.0	48.0	56.0	63.9	71.9
38	8.05	16.1	24.2	32.2	40.3	48.3	56.4	64.4	72.5
40	8.11	16.2	24.3	32.4	40.5	48.6	56.8	64.9	73.0
42	8.17	16.3	24.5	32.7	40.8	49.0	57.2	65.3	73.5
44	8.22	16.4	24.7	32.9	41.1	49.3	57.6	65.8	74.0
46	8.28	16.6	24.8	33.1	41.4	49.7	58.0	66.2	74.5
48	8.34	16.7	25.0	33.4	41.7	50.0	58.4	66.7	75.0
50	8.40	16.8	25.2	33.6	42.0	50.4	58.8	67.2	75.6
52	8.45	16.9	25.4	33.8	42.3	50.7	59.2	67.6	76.1
54	8.51	17.0	25.5	34.0	42.6	51.1	59.6	68.1	76.6
56	8.57	17.1	25.7	34.3	42.8	51.4	60.0	68.5	77.1
58	8.63	17.3	25.9	34.5	43.1	51.8	60.4	69.0	77.6
60	8.68	17.4	26.0	34.7	43.4	52.1	60.8	69.5	78.1
Horizontal dist.	**99.2**	**198.5**	**297.7**	**397.0**	**496.2**	**595.4**	**694.7**	**793.9**	**893.0**
5° 2′	8.74	17.5	26.2	35.0	43.7	52.4	61.2	69.9	78.7
4	8.80	17.6	26.4	35.2	44.0	52.8	61.6	70.4	79.2
6	8.85	17.7	26.6	35.4	44.3	53.1	62.0	70.8	79.7
8	8.91	17.8	26.7	35.6	44.6	53.5	62.4	71.3	80.2
10	8.97	17.9	26.9	35.9	44.8	53.8	62.8	71.7	80.7
12	9.03	18.1	27.1	36.1	45.1	54.2	63.2	72.2	81.2
14	9.08	18.2	27.2	36.3	45.4	54.5	63.6	72.7	81.7
16	9.14	18.3	27.4	36.6	45.7	54.8	64.0	73.1	82.3
18	9.20	18.4	27.6	36.8	46.0	55.2	64.4	73.6	82.8
20	9.25	18.5	27.8	37.0	46.3	55.5	64.8	74.0	83.3
22	9.31	18.6	27.9	37.2	46.6	55.9	65.2	74.5	83.8
24	9.37	18.7	28.1	37.5	46.8	56.2	65.6	74.9	84.3
26	9.43	18.9	28.3	37.7	47.1	56.6	66.0	75.4	84.8
28	9.48	19.0	28.4	37.9	47.4	56.9	66.4	75.9	85.3
30	9.54	19.1	28.6	38.2	47.7	57.2	66.8	76.3	85.9
32	9.60	19.2	28.8	38.4	48.0	57.6	67.2	76.8	86.4
34	9.65	19.3	29.0	38.6	48.3	57.9	67.6	77.2	86.9
36	9.71	19.4	29.1	38.8	48.6	58.3	68.0	77.7	87.4
38	9.77	19.5	29.3	39.1	48.8	58.6	68.4	78.1	87.9
40	9.83	19.7	29.5	39.3	49.1	59.0	68.8	78.6	88.4
42	9.88	19.8	29.6	39.5	49.4	59.3	69.2	79.0	88.9
44	9.94	19.9	29.8	39.8	49.7	59.6	69.6	79.5	89.4
46	10.00	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0
48	10.05	20.1	30.2	40.2	50.3	60.3	70.4	80.4	90.5
50	10.11	20.2	30.3	40.4	50.5	60.7	70.8	80.9	91.0
52	10.17	20.3	30.5	40.7	50.8	61.0	71.2	81.3	91.5
54	10.22	20.4	30.7	40.9	51.1	61.3	71.6	81.8	92.0
56	10.28	20.6	30.8	41.1	51.4	61.7	72.0	82.2	92.5
58	10.33	20.7	31.0	41.4	51.7	62.0	72.4	82.7	93.0
60	10.40	20.8	31.2	41.6	52.0	62.4	72.8	83.2	93.6
Horizontal dist.	**98.9**	**197.8**	**296.7**	**395.6**	**494.5**	**593.5**	**692.4**	**791.3**	**890.2**

TABLE 57 (*Continued*)

STADIA TABLE

Slant Distance	100	200	300	400	500	600	700	800	900
6° 2′	10.45	20.9	31.4	41.8	52.3	62.7	73.2	83.6	94.1
4	10.51	21.0	31.5	42.0	52.5	63.1	73.6	84.1	94.6
6	10.57	21.1	31.7	42.3	52.8	63.4	74.0	84.5	95.1
8	10.62	21.2	31.9	42.5	53.1	63.7	74.4	85.0	95.6
10	10.68	21.4	32.0	42.7	53.4	64.0	74.8	85.4	96.1
12	10.74	21.5	32.2	42.9	53.7	64.4	75.2	85.9	96.6
14	10.79	21.6	32.4	43.2	54.0	64.8	75.5	86.3	97.1
16	10.85	21.7	32.5	43.4	54.2	65.1	75.9	86.8	97.6
18	10.91	21.8	32.7	43.6	54.5	65.4	76.3	87.2	98.2
20	10.96	21.9	32.9	43.8	54.8	65.8	76.7	87.7	98.7
22	11.02	22.0	33.1	44.1	55.1	66.1	77.1	88.2	99.2
24	11.08	22.2	33.2	44.3	55.4	66.5	77.5	88.6	99.7
26	11.13	22.3	33.4	44.5	55.6	66.8	77.9	89.1	100.2
28	11.19	22.4	33.6	44.8	55.9	67.1	78.3	89.5	100.7
30	11.25	22.5	33.7	45.0	56.2	67.5	78.7	90.0	101.2
32	11.30	22.6	33.9	45.2	56.5	67.8	79.1	90.4	101.7
34	11.36	22.7	34.1	45.4	56.8	68.2	79.5	90.9	102.2
36	11.42	22.8	34.2	45.7	57.1	68.5	79.9	91.3	102.7
38	11.47	22.9	34.4	45.9	57.4	68.8	80.3	91.8	103.2
40	11.53	23.1	34.6	46.1	57.6	69.2	80.7	92.2	103.8
42	11.59	23.2	34.8	46.3	57.9	69.5	81.1	92.7	104.3
44	11.64	23.3	34.9	46.6	58.2	69.9	81.5	93.1	104.8
46	11.70	23.4	35.1	46.8	58.5	70.2	81.9	93.6	105.3
48	11.76	23.5	35.3	47.0	58.8	70.5	82.3	94.0	105.8
50	11.81	23.6	35.4	47.2	59.1	70.9	82.7	94.5	106.3
52	11.87	23.7	35.6	47.5	59.3	71.2	83.1	95.0	106.8
54	11.93	23.9	35.8	47.7	59.6	71.6	83.5	95.4	107.3
56	11.98	24.0	35.9	47.9	59.9	71.9	83.9	95.9	107.8
58	12.04	24.1	36.1	48.2	60.2	72.2	84.3	96.3	108.4
60	12.10	24.2	36.3	48.4	60.5	72.6	84.7	96.8	108.9
Horizontal dist.	**98.5**	**197.0**	**295.5**	**394.0**	**492.6**	**591.1**	**689.6**	**788.1**	**886.6**
7° 2′	12.15	24.3	36.5	48.6	60.8	72.9	85.1	97.2	109.4
4	12.21	24.4	36.6	48.8	61.0	73.2	85.5	97.7	109.9
6	12.26	24.5	36.8	49.1	61.3	73.6	85.8	98.1	110.4
8	12.32	24.6	37.0	49.3	61.6	73.9	86.2	98.6	110.9
10	12.38	24.8	37.1	49.5	61.9	74.3	86.6	99.0	111.4
12	12.43	24.9	37.3	49.7	62.2	74.6	87.0	99.5	111.9
14	12.49	25.0	37.5	50.0	62.4	74.9	87.4	99.9	112.4
16	12.55	25.1	37.6	50.2	62.7	75.3	87.8	100.4	112.9
18	12.60	25.2	37.8	50.4	63.0	75.6	88.2	100.8	113.4
20	12.66	25.3	38.0	50.6	63.3	75.9	88.6	101.3	113.9
22	12.71	25.4	38.1	50.9	63.6	76.3	89.0	101.7	114.4
24	12.77	25.5	38.3	51.1	63.8	76.6	89.4	102.2	114.9
26	12.83	25.7	38.5	51.3	64.1	77.0	89.8	102.6	115.4
28	12.88	25.8	38.6	51.5	64.4	77.3	90.2	103.1	115.9
30	12.94	25.9	38.8	51.8	64.7	77.6	90.6	103.5	116.4
32	13.00	26.0	39.0	52.0	65.0	78.0	91.0	104.0	117.0
34	13.05	26.1	39.2	52.2	65.3	78.3	91.4	104.4	117.5
36	13.11	26.2	39.3	52.4	65.5	78.6	91.7	104.9	118.0
38	13.16	26.3	39.5	52.7	65.8	79.0	92.1	105.3	118.5
40	13.22	26.4	39.7	52.9	66.1	79.3	92.5	105.8	119.0
42	13.28	26.6	39.8	53.1	66.4	79.7	92.9	106.2	119.5
44	13.33	26.7	40.0	53.3	66.7	80.0	93.2	106.7	120.0
46	13.39	26.8	40.2	53.6	66.9	80.3	93.7	107.1	120.5
48	13.44	26.9	40.3	53.8	67.2	80.7	94.1	107.6	121.0
50	13.50	27.0	40.5	54.0	67.5	81.0	94.5	108.0	121.5
52	13.56	27.1	40.7	54.2	67.8	81.3	94.9	108.5	122.0
54	13.61	27.2	40.8	54.5	68.1	81.7	95.3	108.9	122.5
56	13.67	27.3	41.0	54.7	68.3	82.0	95.7	109.4	123.0
58	13.73	27.5	41.2	54.9	68.6	82.3	96.1	109.8	123.5
60	13.78	27.6	41.3	55.1	68.9	82.7	96.4	110.3	124.0
Horizontal dist.	**98.1**	**196.1**	**294.2**	**392.2**	**490.3**	**588.4**	**686.4**	**784.5**	**882.6**

TABLE 57 (*Continued*)

STADIA TABLF

Slant Distance	100	200	300	400	500	600	700	800	900
8° 5′	13.92	27.8	41.8	55.7	69.6	83.5	97.4	111.4	125.3
10	14.06	28.1	42.2	56.2	70.3	84.4	98.4	112.5	126.6
15	14.20	28.4	42.6	56.8	71.0	85.2	99.4	113.6	127.8
20	14.34	28.7	43.0	57.4	71.7	86.0	100.4	114.7	129.1
25	14.48	29.0	43.4	57.9	72.4	86.9	101.4	115.8	130.3
30	14.62	29.2	43.9	58.5	73.1	87.7	102.3	116.9	131.6
35	14.76	29.5	44.2	59.0	73.7	88.4	103.1	117.8	132.5
40	14.90	29.8	44.7	59.6	74.5	89.4	104.3	119.2	134.1
45	15.04	30.1	45.1	60.1	75.2	90.2	105.2	120.3	135.3
50	15.17	30.3	45.5	60.7	75.9	91.0	106.2	121.4	136.6
55	15.31	30.6	45.9	61.2	76.6	91.9	107.2	122.5	137.8
60	15.45	30.9	46.4	61.8	77.3	92.7	108.2	123.6	139.1
Horizontal dist.	**97.5**	**195.1**	**292.7**	**390.2**	**487.8**	**585.3**	**682.9**	**780.4**	**878.0**
9° 5′	15.59	31.2	46.8	62.4	77.9	93.5	109.1	124.7	140.3
10	15.73	31.5	47.2	62.9	78.6	94.5	110.2	125.9	141.6
15	15.86	31.7	47.6	63.5	79.3	95.2	111.1	126.9	142.8
20	16.00	32.0	48.0	64.0	80.0	96.0	112.0	128.0	144.0
25	16.14	32.3	48.4	64.6	80.7	96.8	113.0	129.0	145.3
30	16.28	32.6	48.8	65.1	81.4	97.7	113.9	130.2	146.5
35	16.42	32.8	49.2	65.7	82.1	98.5	114.9	131.3	147.7
40	16.55	33.1	49.7	66.2	82.8	99.3	115.9	132.4	148.0
45	16.69	33.4	50.1	66.8	83.5	100.1	116.8	133.5	150.2
50	16.83	33.7	50.5	67.3	84.4	101.0	117.8	134.6	151.4
55	16.96	33.9	50.9	67.9	84.8	101.8	118.7	135.7	152.7
60	17.10	34.2	51.3	68.4	85.5	102.6	119.7	136.8	153.9
Horizontal dist.	**97.0**	**194.0**	**291.0**	**387.9**	**484.9**	**581.9**	**678.9**	**775.9**	**872.9**
10° 5′	17.24	34.5	51.7	68.9	86.2	103.4	120.7	137.9	155.1
10	17.37	34.7	52.1	69.5	86.9	104.2	121.6	139.0	156.4
15	17.51	35.0	52.5	70.0	87.6	105.1	122.6	140.1	157.6
20	17.65	35.3	52.9	70.6	88.2	105.9	123.5	141.2	158.8
25	17.78	35.6	53.3	71.1	88.9	106.7	124.5	142.3	160.0
30	17.92	35.8	53.8	71.7	89.6	107.5	125.4	143.3	161.3
35	18.05	36.1	54.2	72.2	90.3	108.3	126.4	144.4	162.5
40	18.19	36.4	54.6	72.7	90.9	109.1	127.3	145.5	163.7
45	18.37	36.6	55.0	73.4	91.8	110.1	128.5	146.6	165.3
50	18.46	36.9	55.4	73.8	92.8	110.8	129.2	147.7	166.1
55	18.60	37.2	55.8	74.4	93.0	111.6	130.2	148.8	167.4
60	18.73	37.5	56.2	74.9	93.7	112.4	131.1	149.8	168.5
Horizontal dist.	**96.4**	**192.7**	**289.1**	**385.4**	**481.8**	**578.2**	**684.5**	**770.9**	**867.7**
11° 5′	18.86	37.7	56.6	75.5	94.3	113.2	132.1	150.9	169.8
10	19.00	38.0	57.0	76.0	95.0	114.0	133.0	152.0	171.0
15	19.13	38.3	57.4	76.5	95.7	114.8	133.9	153.1	172.2
20	19.27	38.5	57.8	77.1	96.3	115.6	134.9	154.1	173.4
25	19.40	38.8	58.2	77.6	97.0	116.4	135.8	155.2	174.6
30	19.54	39.1	58.6	78.1	97.7	117.2	136.8	156.3	175.8
35	19.67	39.3	59.0	78.7	98.4	118.0	137.7	157.4	177.0
40	19.80	39.6	59.4	79.2	99.0	118.8	138.6	158.4	178.2
45	19.94	39.9	59.8	79.7	99.7	119.6	139.6	159.5	179.4
50	20.07	40.1	60.2	80.3	100.4	120.4	140.5	160.6	180.6
55	20.20	40.4	60.6	80.8	101.0	121.2	141.4	161.6	181.8
60	20.34	40.7	61.0	81.4	101.7	122.0	142.4	162.7	183.0
Horizontal dist.	**95.7**	**191.3**	**287.0**	**382.7**	**478.4**	**474.1**	**669.7**	**765.4**	**861.1**

TABLE 57 (*Continued*)

STADIA TABLE

Slant Distance	100	200	300	400	500	600	700	800	900
12° 5′......	20.47	40.9	61.4	81.9	102.3	122.8	143.3	163.8	184.2
10	20.60	41.2	61.8	82.4	103.0	123.6	144.2	164.8	185.4
15	20.73	41.5	62.2	82.9	103.7	124.4	145.1	165.9	186.6
20	20.87	41.7	62.6	83.5	104.3	125.2	146.1	166.9	187.8
25	21.00	42.0	63.0	84.0	105.0	126.0	147.0	168.0	189.0
30	21.13	42.3	63.4	84.5	105.7	126.8	147.9	169.0	190.2
35	21.26	42.5	63.8	85.1	106.3	127.6	148.8	170.1	191.4
40	21.39	42.8	64.2	85.6	107.0	128.4	149.8	171.2	192.5
45	21.52	43.1	64.6	86.1	107.6	129.2	150.7	172.2	193.7
50	21.66	43.3	65.0	86.6	108.3	129.9	151.6	173.2	194.9
55	21.79	43.6	65.4	87.2	108.9	130.7	152.5	174.3	196.1
60	21.92	43.8	65.7	87.7	109.6	131.5	153.4	175.3	197.3
Horizontal dist.	**94.9**	**189.9**	**284.8**	**379.8**	**474.7**	**569.6**	**664.6**	**759.5**	**854.5**
13° 5′......	22.05	44.1	66.1	88.2	110.2	132.3	154.3	176.3	198.4
10	22.18	44.4	66.5	88.7	110.9	133.1	155.8	177.4	199.6
15	22.31	44.6	66.9	89.2	111.6	133.9	156.2	178.5	200.8
20	22.44	44.9	67.3	89.8	112.2	134.6	157.1	179.5	202.0
25	22.57	45.1	67.7	90.3	112.8	135.4	158.0	180.6	203.1
30	22.70	45.4	68.1	90.8	113.5	136.2	158.9	181.6	204.3
35	22.83	45.7	68.5	91.3	114.1	137.0	159.8	182.6	205.5
40	22.96	45.9	68.9	91.8	114.8	137.7	160.7	183.7	206.6
45	23.09	46.2	69.3	92.4	115.4	138.5	161.6	184.7	207.8
50	23.22	46.4	69.6	92.9	116.1	139.3	162.5	185.7	208.9
55	23.35	46.7	70.0	93.4	116.7	140.1	163.4	186.8	210.1
60	23.47	46.9	70.4	93.9	117.4	140.8	164.8	187.8	211.3
Horizontal dist.	**94.2**	**188.3**	**282.4**	**376.6**	**470.7**	**564.9**	**659.0**	**753.2**	**847.3**
14° 5′......	23.60	47.2	70.8	94.4	118.0	141.6	165.2	188.8	212.4
10	23.73	47.5	71.2	94.9	118.6	142.4	166.1	189.8	213.6
15	23.86	47.7	71.6	95.4	119.3	143.2	167.0	190.9	214.7
20	23.99	48.0	72.0	95.9	119.9	143.9	167.9	191.9	215.9
25	24.11	48.2	72.8	96.5	120.6	144.7	168.8	192.9	217.0
30	24.24	48.5	72.7	97.0	121.2	145.4	169.7	193.9	218.2
35	24.37	48.7	73.1	97.5	121.8	146.2	170.6	194.9	219.3
40	24.49	49.0	73.5	98.0	122.5	147.0	171.5	196.0	220.4
45	24.62	49.2	73.9	98.5	123.1	147.7	172.8	197.0	221.6
50	24.75	49.5	74.2	99.0	123.7	148.5	173.2	198.0	222.7
55	24.87	49.7	74.6	99.5	124.4	149.2	174.1	199.0	223.9
60	25.00	50.0	75.0	100.0	125.0	150.0	175.0	200.0	225.0
Horizontal dist.	**93.3**	**186.6**	**279.9**	**373.2**	**466.5**	**559.8**	**683.1**	**786.4**	**839.7**
15° 5′......	25.13	50.3	75.4	100.5	125.6	150.8	175.9	201.0	226.1
10	25.25	50.5	75.8	101.0	126.3	151.5	176.8	202.0	227.3
15	25.38	50.8	76.1	101.5	126.9	152.3	177.6	203.0	228.4
20	25.50	51.0	76.5	102.0	127.5	153.0	178.5	204.0	229.5
25	25.63	51.3	76.9	102.5	128.1	153.8	179.4	205.0	230.6
30	25.75	51.5	77.3	103.0	128.8	154.5	180.3	206.0	231.8
35	25.88	51.8	77.6	103.5	129.4	155.3	181.1	207.0	232.9
40	26.00	52.0	78.0	104.0	130.0	156.0	182.0	208.0	234.0
45	26.12	52.2	78.4	104.5	130.6	156.7	182.9	209.0	235.1
50	26.25	52.5	78.7	105.0	131.2	157.5	183.7	210.0	236.2
55	26.37	52.7	79.1	105.5	131.9	158.2	184.6	211.0	237.4
60	26.50	53.0	79.5	106.0	132.5	159.0	185.5	212.0	238.5
Horizontal dist.	**92.4**	**184.8**	**277.2**	**369.6**	**462.0**	**554.4**	**646.8**	**739.2**	**831.6**

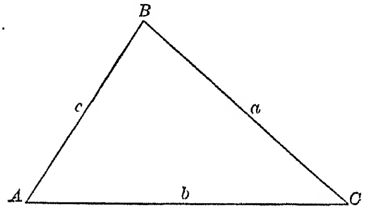
TABLE 57 (*Concluded*)

Stadia Table.

Slant Distance	100	200	300	400	500	600	700	800	900
16° 5′	26.62	53.2	79.9	106.5	133.1	159.7	186.3	213.0	239.6
10	26.74	53.5	80.2	107.0	133.7	160.5	187.2	213.9	240.7
15	26.86	53.7	80.6	107.5	134.3	161.2	188.0	214.9	241.8
20	26.99	54.0	81.0	108.0	134.9	161.9	188.9	215.9	242.9
25	27.11	54.2	81.3	108.4	135.6	162.7	189.8	216.9	244.0
30	27.23	54.5	81.7	108.9	136.2	163.4	190.6	217.9	245.1
35	27.35	54.7	82.1	109.4	136.8	164.1	191.5	218.8	246.2
40	27.48	55.0	82.4	109.9	137.4	164.9	192.4	219.8	247.3
45	27.60	55.2	82.8	110.4	138.0	165.6	193.2	220.8	248.4
50	27.72	55.4	83.2	110.9	138.6	166.3	194.0	221.7	249.5
55	27.84	55.7	83.5	111.4	139.2	167.0	194.9	222.7	250.6
60	27.96	55.9	83.9	111.8	139.8	167.8	195.7	223.7	251.6
Horizontal dist.	91.4	183	274	366	457	549	640	732	823
17° 5′	28.08	56.2	84.2	112.3	140.4	168.5	196.6	224.6	252.7
10	28.20	56.4	84.6	112.8	141.0	169.2	197.4	225.6	253.8
15	28.32	56.6	85.0	113.3	141.6	169.9	198.2	226.6	254.9
20	28.44	56.9	85.3	113.8	142.2	170.6	199.1	227.5	256.0
25	28.56	57.1	85.7	114.2	142.8	171.4	199.9	228.5	257.0
30	28.68	57.4	86.0	114.7	143.4	172.1	200.8	229.4	258.1
35	28.80	57.6	86.4	115.2	144.0	172.8	201.6	230.4	259.2
40	28.92	57.8	86.7	115.7	144.6	173.5	202.4	231.3	260.2
45	29.04	58.1	87.1	116.1	145.2	174.2	203.2	232.3	261.3
50	29.15	58.3	87.5	116.6	145.8	174.9	204.1	233.2	262.4
55	29.27	58.5	87.8	117.1	146.4	175.6	204.9	234.2	263.4
60	29.39	58.8	88.2	117.6	146.9	176.3	205.7	235.1	264.5
Horizontal dist.	90.4	181	271	362	452	543	633	724	814
18° 5′	29.51	59.0	88.5	118.0	147.5	177.0	206.5	236.1	265.6
10	29.62	59.2	88.9	118.5	148.1	177.7	207.4	237.0	266.6
15	29.74	59.5	89.2	119.0	148.7	178.4	208.2	237.9	267.7
20	29.86	59.7	89.6	119.4	149.3	179.1	209.0	238.9	268.7
25	29.97	59.9	89.9	119.9	149.9	179.8	209.8	239.8	269.8
30	30.09	60.2	90.3	120.4	150.5	180.5	210.6	240.7	270.8
35	30.21	60.4	90.6	120.8	151.0	181.2	211.4	241.7	271.9
40	30.32	60.6	91.0	121.3	151.6	181.9	212.3	242.6	272.9
45	30.44	60.9	91.3	121.8	152.2	182.6	213.1	243.5	273.9
50	30.55	61.1	91.7	122.2	152.8	183.3	213.9	244.4	275.0
55	30.67	61.3	92.0	122.7	153.3	184.0	214.7	245.4	276.0
60	30.78	61.6	92.3	123.1	153.9	184.7	215.5	246.3	277.0
Horizontal dist.	89.4	179	268	358	447	536	626	715	805
19° 5′	30.90	61.8	92.7	123.6	154.5	185.4	216.3	247.2	278.1
10	31.01	62.0	93.0	124.0	155.1	186.1	217.1	248.1	279.1
15	31.12	62.3	93.4	124.5	155.6	186.8	217.9	249.0	280.1
20	31.24	62.5	93.7	125.0	156.2	187.4	218.7	249.9	281.2
25	31.35	62.7	94.1	125.4	156.8	188.1	219.5	250.8	282.2
30	31.47	62.9	94.4	125.9	157.3	188.8	220.3	251.7	283.2
35	31.58	63.2	94.7	126.3	157.9	189.5	221.1	252.6	284.2
40	31.69	63.4	95.1	126.8	158.5	190.1	221.8	253.5	285.2
45	31.80	63.6	95.4	127.2	159.0	190.8	222.6	254.4	286.2
50	31.92	63.8	95.7	127.7	159.6	191.5	223.4	255.3	287.2
55	32.03	64.1	96.1	128.1	160.1	192.2	224.2	256.2	288.3
60	32.14	64.3	96.4	128.6	160.7	192.8	225.0	257.1	289.3
Horizontal dist.	88.3	177	265	353	442	530	618	706	795

TABLE 58.—TRIGONOMETRIC FORMULÆ

SOLUTION OF OBLIQUE TRIANGLES.



	GIVEN.	SOUGHT.	FORMULÆ.
1	A, B, a	C, b, c	$C = 180° - (A + B), \quad b = \frac{a}{\sin A} \cdot \sin B,$ $c = \frac{a}{\sin A} \sin (A + B)$
2	A, a, b	B, C, c	$\sin B = \frac{\sin A}{a} \cdot b, \quad C = 180° - (A + B),$ $c = \frac{a}{\sin A} \cdot \sin C.$
3	C, a, b	$\frac{1}{2}(A + B)$	$\frac{1}{2}(A + B) = 90° - \frac{1}{2} C$
4		$\frac{1}{2}(A - B)$	$\tan \frac{1}{2}(A - B) = \frac{a - b}{a + b} \tan \frac{1}{2}(A + B)$
5		A, B	$A = \frac{1}{2}(A + B) + \frac{1}{2}(A - B),$ $B = \frac{1}{2}(A + B) - \frac{1}{2}(A - B)$
6		c	$c = (a + b) \frac{\cos \frac{1}{2}(A + B)}{\cos \frac{1}{2}(A - B)} = (a - b) \frac{\sin \frac{1}{2}(A + B)}{\sin \frac{1}{2}(A - B)}$
7		area	$K = \frac{1}{2} a\, b \sin C.$
8	a, b, c	A	Let $s = \frac{1}{2}(a + b + c)$; $\sin \frac{1}{2} A = \sqrt{\frac{(s-b)\,(s-c)}{b\,c}}$
9			$\cos \frac{1}{2} A = \sqrt{\frac{s(s-a)}{b\,c}}$; $\tan \frac{1}{2} A = \sqrt{\frac{(s-b)(s-c)}{s\,(s-a)}}$
10			$\sin A = \frac{2\sqrt{s\,(s-a)\,(s-b)\,(s-c)}}{b\,c}$; $\text{vers } A = \frac{2\,(s-b)\,(s-c)}{b\,c}$
11		area	$K = \sqrt{s\,(s-a)\,(s-b)\,(s-c)}$
12	A, B, C, a	area	$K = \frac{a^2 \sin B \cdot \sin C}{2 \sin A}$

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TABLE 58 (*Continued*).—TRIGONOMETRIC FORMULÆ

	GENERAL FORMULÆ.
13	$\sin A = \dfrac{1}{\operatorname{cosec} A} = \sqrt{1-\cos^2 A} = \tan A \cos A$
14	$\sin A = 2 \sin \tfrac{1}{2} A \cos \tfrac{1}{2} A = \operatorname{vers} A \cot \tfrac{1}{2} A$
15	$\sin A = \sqrt{\tfrac{1}{2} \operatorname{vers} 2A} = \sqrt{\tfrac{1}{2}(1-\cos 2A)}$
16	$\cos A = \dfrac{1}{\sec A} = \sqrt{1-\sin^2 A} = \cot A \sin A$
17	$\cos A = 1 - \operatorname{vers} A = 2\cos^2 \tfrac{1}{2} A - 1 = 1 - 2\sin^2 \tfrac{1}{2} A$
18	$\cos A = \cos^2 \tfrac{1}{2} A - \sin^2 \tfrac{1}{2} A = \sqrt{\tfrac{1}{2} + \tfrac{1}{2}\cos 2A}$
19	$\tan A = \dfrac{1}{\cot A} = \dfrac{\sin A}{\cos A} = \sqrt{\sec^2 A - 1}$
20	$\tan A = \sqrt{\dfrac{1}{\cos^2 A} - 1} = \dfrac{\sqrt{1-\cos^2 A}}{\cos A} = \dfrac{\sin 2A}{1+\cos 2A}$
21	$\tan A = \dfrac{1-\cos 2A}{\sin 2A} = \dfrac{\operatorname{vers} 2A}{\sin 2A} = \operatorname{exsec} A \cot \tfrac{1}{2} A$
22	$\cot A = \dfrac{1}{\tan A} = \dfrac{\cos A}{\sin A} = \sqrt{\operatorname{cosec}^2 A - 1}$
23	$\cot A = \dfrac{\sin 2A}{1-\cos 2A} = \dfrac{\sin 2A}{\operatorname{vers} 2A} = \dfrac{1+\cos 2A}{\sin 2A}$
24	$\cot A = \dfrac{\tan \tfrac{1}{2} A}{\operatorname{exsec} A}$
25	$\operatorname{vers} A = 1 - \cos A = \sin A \tan \tfrac{1}{2} A = 2\sin^2 \tfrac{1}{2} A$
26	$\operatorname{vers} A = \operatorname{exsec} A \cos A$
27	$\operatorname{exsec} A = \sec A - 1 = \tan A \tan \tfrac{1}{2} A = \dfrac{\operatorname{vers} A}{\cos A}$
28	$\sin \tfrac{1}{2} A = \sqrt{\dfrac{1-\cos A}{2}} = \sqrt{\dfrac{\operatorname{vers} A}{2}}$
29	$\sin 2A = 2 \sin A \cos A$
30	$\cos \tfrac{1}{2} A = \sqrt{\dfrac{1+\cos A}{2}}$
31	$\cos 2A = 2\cos^2 A - 1 = \cos^2 A - \sin^2 A = 1 - 2\sin^2 A$

TABLE 58 (*Concluded*).—TRIGONOMETRIC FORMULÆ

GENERAL FORMULÆ.

32 $\tan \frac{1}{2} A = \dfrac{\tan A}{1 + \sec A} = \operatorname{cosec} A - \cot A = \dfrac{1 - \cos A}{\sin A} = \sqrt{\dfrac{1 - \cos A}{1 + \cos A}}$

33 $\tan 2 A = \dfrac{2 \tan A}{1 - \tan^2 A}$

34 $\cot. \frac{1}{2} A = \dfrac{\sin A}{\operatorname{vers} A} = \dfrac{1 + \cos A}{\sin A} = \dfrac{1}{\operatorname{cosec} A - \cot A}$

35 $\cot 2 A = \dfrac{\cot^2 A - 1}{2 \cot A}$

36 $\operatorname{vers} \frac{1}{2} A = \dfrac{\frac{1}{2} \operatorname{vers} A}{1 + \sqrt{1 - \frac{1}{2} \operatorname{vers} A}} = \dfrac{1 - \cos A}{2 + \sqrt{2 (1 + \cos A)}}$

37 $\operatorname{vers} 2 A = 2 \sin^2 A = 2 \sin A \cos A \tan A$

38 $\operatorname{exsec} \frac{1}{2} A = \dfrac{1 - \cos A}{(1 + \cos A) + \sqrt{2 (1 + \cos A)}}$

39 $\operatorname{exsec} 2 A = \dfrac{2 \tan^2 A}{1 - \tan^2 A}$

40 $\sin (A \pm B) = \sin A \,.\, \cos B \pm \sin B \,.\, \cos A$

41 $\cos (A \pm B) = \cos A \,.\, \cos B \mp \sin A \,.\, \sin B$

42 $\sin A + \sin B = 2 \sin \frac{1}{2} (A + B) \cos \frac{1}{2} (A - B)$

43 $\sin A - \sin B = 2 \cos \frac{1}{2} (A + B) \sin \frac{1}{2} (A - B)$

44 $\cos A + \cos B = 2 \cos \frac{1}{2} (A + B) \cos \frac{1}{2} (A - B)$

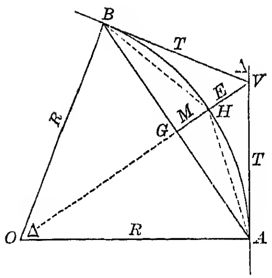
45 $\cos B - \cos A = 2 \sin \frac{1}{2} (A + B) \sin \frac{1}{2} (A - B)$

46 $\sin^2 A - \sin^2 B = \cos^2 B - \cos^2 A = \sin (A + B) \sin (A - B)$

47 $\cos^2 A - \sin^2 B = \cos (A + B) \cos (A - B)$

48 $\tan A + \tan B = \dfrac{\sin (A + B)}{\cos A \,.\, \cos B}$

49 $\tan A - \tan B = \dfrac{\sin (A - B)}{\cos A \,.\, \cos B}$



D = Degree of curve.
L = Length of curve.
C = Length of long chord = $A\ B$.

TABLE 59.—CURVE FORMULÆ

	GIVEN.	SOUGHT.	FORMULÆ.
1	D	R	$R = \frac{50}{\sin \frac{1}{2} D}$
2	R	D	$\sin \frac{1}{2} D = \frac{50}{R}$
3	Δ, D	L	$L = 100 \frac{\Delta}{D}$
4	D, L	Δ	$\Delta = \frac{DL}{100}$
5	Δ, L	D	$D = 100 \frac{\Delta}{L}$
6	R, Δ	T	$T = R \tan \frac{1}{2} \Delta$
7	"	C	$C = 2 R \sin \frac{1}{2} \Delta$
8	"	M	$M = R \operatorname{vers} \frac{1}{2} \Delta$
9	"	E	$E = R \operatorname{exsec} \frac{1}{2} \Delta$
10	T, Δ	R	$R = T \cot \frac{1}{2} \Delta$
11	"	E	$E = T \tan \frac{1}{4} \Delta$
12	"	C	$C = 2 T \cos \frac{1}{2} \Delta$
13	"	M	$M = T \cot \frac{1}{2} \Delta \,.\, \operatorname{vers} \frac{1}{2} \Delta$
14	E, Δ	R	$R = \frac{E}{\operatorname{exsec} \frac{1}{2} \Delta}$
15	"	T	$T = E \cot \frac{1}{4} \Delta$
16	"	C	$C = 2 E \frac{\sin \frac{1}{2} \Delta}{\operatorname{exsec} \frac{1}{2} \Delta}$
17	"	M	$M = E \cos \frac{1}{2} \Delta$
18	C, Δ	R	$R = \frac{C}{2 \sin \frac{1}{2} \Delta}$
19	"	M	$M = \frac{1}{2} C \tan \frac{1}{4} \Delta$
20	"	T	$T = \frac{C}{2 \cos \frac{1}{2} \Delta}$
21	"	E	$E = \frac{1}{2} C \frac{\operatorname{exsec} \frac{1}{2} \Delta}{\sin \frac{1}{2} \Delta}$
22	M, Δ	R	$R = \frac{M}{\operatorname{vers} \frac{1}{2} \Delta}$
23	"	C	$C = 2 M \cot \frac{1}{4} \Delta$
24	"	T	$T = M \frac{\tan \frac{1}{2} \Delta}{\operatorname{vers} \frac{1}{2} \Delta}$
25	"	E	$E = \frac{M}{\cos \frac{1}{2} \Delta}$

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TABLE 59 (*Continued*).—CURVE FORMULÆ

	GIVEN.	SOUGHT.	FORMULÆ.
26	R, T	Δ	$\tan \frac{1}{2}\Delta = \frac{T}{R}$
27	"	"	$\sin \frac{1}{2}\Delta = \frac{T}{\sqrt{T^2 + R^2}}$
28	R, C	Δ	$\sin \frac{1}{2}\Delta = \frac{C}{2R}$
29	"	"	$\cos \frac{1}{2}\Delta = \frac{1}{R}\sqrt{\left(R + \frac{C}{2}\right)\left(R - \frac{C}{2}\right)}$
30	R, M	Δ	$\text{vers} \frac{1}{2}\Delta = \frac{M}{R}$
31	"	"	$\cos \frac{1}{2}\Delta = \frac{R - M}{R}$
32	R, E	Δ	$\text{exsec} \frac{1}{2}\Delta = \frac{E}{R}$
33	"	"	$\cos \frac{1}{2}\Delta = \frac{R}{R + E}$
34	T, C	Δ	$\cos \frac{1}{2}\Delta = \frac{C}{2T}$
35	"	"	$\tan \frac{1}{4}\Delta = \sqrt{\frac{2T - C}{2T + C}}$
36	T, E	Δ	$\tan \frac{1}{4}\Delta = \frac{E}{T}$
37	"	"	$\cos \frac{1}{2}\Delta = \frac{T^2 - E}{T^2 + E^2}$
38	C, M	Δ	$\tan \frac{1}{4}\Delta = \frac{2M}{C}$
39	"	"	$\cos \frac{1}{2}\Delta = \frac{C^2 - 4M^2}{C^2 + 4M^2}$
40	M, E	Δ	$\cos \frac{1}{2}\Delta = \frac{M}{E}$
41	"	"	$\tan \frac{1}{4}\Delta = \sqrt{\frac{E - M}{E + M}}$
42	R, T	C	$C = \frac{2TR}{\sqrt{T^2 + R^2}}$
43	"	M	$M = R - \frac{R^2}{\sqrt{T^2 + R^2}}$
44	"	E	$E = \sqrt{T^2 + R^2} - R$
45	R, C	T	$T = \frac{CR}{2\sqrt{\left(R + \frac{C}{2}\right)\left(R - \frac{C}{2}\right)}}$
46	"	M	$M = R - \sqrt{(R + \frac{1}{2}C)(R - \frac{1}{2}C)}$
47	"	E	$E = \frac{R^2}{\sqrt{(R + \frac{1}{2}C)(R - \frac{1}{2}C)}} - R$

TABLE 59 (*Concluded*).—CURVE FORMULÆ

	GIVEN.	SOUGHT.	FORMULÆ.
48	R, M	T	$T = \frac{R\sqrt{M(2R-M)}}{R-M}$
49	"	C	$C = 2\sqrt{M(2R-M)}$
50	"	E	$E = \frac{RM}{R-M}$
51	R, E	T	$T = \sqrt{E(2R+E)}$
52	"	C	$C = \frac{2R\sqrt{E(2R+E)}}{R+E}$
53	"	M	$M = \frac{RE}{R+E}$
54	T, C	R	$R = \frac{CT}{\sqrt{(2T+C)(2T-C)}}$
55	"	M	$M = \frac{1}{2} C \sqrt{\frac{2T-C}{2T+C}}$
56	"	E	$E = T \sqrt{\frac{2T-C}{2T+C}}$
57	T, E	R	$R = \frac{(T+E)(T-E)}{2E}$
58	"	C	$C = \frac{2T(T^2-E^2)}{T^2+E^2}$
59	"	M	$M = \frac{E(T^2-E^2)}{T^2+E^2}$
60	C, M	R	$R = \frac{M^2+(\frac{1}{2}C)^2}{2M}$
61	"	T	$T = \frac{C(C^2+4M^2)}{2(C^2-4M^2)}$
62	"	E	$E = M\frac{C^2+4M^2}{C^2-4M^2}$
63	M, E	R	$R = \frac{EM}{E-M}$
64	"	T	$T = E\sqrt{\frac{E+M}{E-M}}$
65	"	C	$C = 2M\sqrt{\frac{E+M}{E-M}}$
66	T, M	R	$R^3 - R^2\frac{M^2+T^2}{2M} + RT^2 - \frac{1}{2}MT^2 = 0$
67	"	E	$E^3 + E^2M - ET^2 + MT^2 = 0$
68	"	C	$C^3 + 2TC^2 + 4M^2C - 8M^2T = 0$
69	C, E	R	$R^3 + R^2\frac{4E^2-C^2}{8E} - R\frac{C^2}{4} - \frac{C^2E}{8} = 0$
70	"	T	$2T^3 - T^2C - 2TE^2 - CE^2 = 0$
71	"	M	$M^3 + M^2E + M\frac{C^2}{4} - \frac{C^2E}{4} = 0$

Common Logarithms

TABLE 60

n	0	1	2	3	4	5	6	7	8	9
10	00000	00432	00860	01284	01703	02119	02531	02938	03342	03743
11	04139	04532	04922	05308	05690	06070	06446	06819	07188	07555
12	07918	08279	08636	08991	09342	09691	10037	10380	10721	11059
13	11394	11727	12057	12385	12710	13033	13354	13672	13988	14301
14	14613	14922	15229	15534	15836	16137	16435	16732	17026	17319
15	17609	17898	18184	18469	18752	19033	19312	19590	19866	20140
16	20412	20683	20952	21219	21484	21748	22011	22272	22531	22789
17	23045	23300	23553	23805	24055	24304	24551	24797	25042	25285
18	25527	25768	26007	26245	26482	26717	26951	27184	27416	27646
19	27875	28103	28330	28556	28780	29003	29226	29447	29667	29885
20	30103	30320	30535	30750	30963	31175	31387	31597	31806	32015
21	32222	32428	32634	32838	33041	33244	33445	33646	33846	34044
22	34242	34439	34635	34830	35025	35218	35411	35603	35793	35984
23	36173	36361	36549	36736	36922	37107	37291	37475	37658	37840
24	38021	38202	38382	38561	38739	38917	39094	39270	39445	39620
25	39794	39967	40140	40312	40483	40654	40824	40993	41162	41330
26	41497	41664	41830	41996	42160	42325	42488	42651	42813	42975
27	43136	43297	43457	43616	43775	43933	44091	44248	44404	44560
28	44716	44871	45025	45179	45332	45484	45637	45788	45939	46090
29	46240	46389	46538	46687	46835	46982	47129	47276	47422	47567
30	47712	47857	48001	48144	48287	48430	48572	48714	48855	48996
31	49136	49276	49415	49554	49693	49831	49969	50106	50243	50379
32	50515	50651	50786	50920	51055	51188	51322	51455	51587	51720
33	51851	51983	52114	52244	52375	52504	52634	52763	52892	53020
34	53148	53275	53403	53529	53656	53782	53908	54033	54158	54283
35	54407	54531	54654	54777	54900	55023	55145	55267	55388	55509
36	55630	55751	55871	55991	56110	56229	56348	56467	56585	56703
37	56820	56937	57054	57171	57287	57403	57519	57634	57749	57864
38	57978	58092	58206	58320	58433	58546	58659	58771	58883	58995
39	59106	59218	59329	59439	59550	59660	59770	59879	59988	60097
40	60206	60314	60423	60531	60638	60746	60853	60959	61066	61172
41	61278	61384	61490	61595	61700	61805	61909	62014	62118	62221
42	62325	62428	62531	62634	62737	62839	62941	63043	63144	63246
43	63347	63448	63548	63649	63749	63849	63949	64048	64147	64246
44	64345	64444	64542	64640	64738	64836	64933	65031	65128	65225
45	65321	65418	65514	65610	65706	65801	65896	65992	66087	66181
46	66276	66370	66464	66558	66652	66745	66839	66932	67025	67117
47	67210	67302	67394	67486	67578	67669	67761	67852	67943	68034
48	68124	68215	68305	68395	68485	68574	68664	68753	68842	68931
49	69020	69108	69197	69285	69373	69461	69548	69636	69723	69810
50	69897	69984	70070	70157	70243	70329	70415	70501	70586	70672
51	70757	70842	70927	71012	71096	71181	71265	71349	71433	71517
52	71600	71684	71767	71850	71933	72016	72099	72181	72263	72346
53	72428	72509	72591	72673	72754	72835	72916	72997	73078	73159
54	73239	73320	73400	73480	73560	73640	73719	73799	73878	73957
	0	1	2	3	4	5	6	7	8	9

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of Numbers from 000 to 999

n	0	1	2	3	4	5	6	7	8	9
55	74036	74115	74194	74273	74351	74429	74507	74586	74663	74741
56	74819	74896	74974	75051	75128	75205	75282	75358	75435	75511
57	75587	75664	75740	75815	75891	75967	76042	76118	76193	76268
58	76343	76418	76492	76567	76641	76716	76790	76864	76938	77012
59	77085	77159	77232	77305	77379	77452	77525	77597	77670	77743
60	77815	77887	77960	78032	78104	78176	78247	78319	78390	78462
61	78533	78604	78675	78746	78817	78888	78958	79029	79099	79169
62	79239	79309	79379	79449	79518	79588	79657	79727	79796	79865
63	79934	80003	80072	80140	80209	80277	80346	80414	80482	80550
64	80618	80686	80754	80821	80889	80956	81023	81090	81158	81224
65	81291	81358	81425	81491	81558	81624	81690	81757	81823	81889
66	81954	82020	82086	82151	82217	82282	82347	82413	82478	82543
67	82607	82672	82737	82802	82866	82930	82995	83059	83123	83187
68	83251	83315	83378	83442	83506	83569	83632	83696	83759	83822
69	83885	83948	84011	84073	84136	84198	84261	84323	84386	84448
70	84510	84572	84634	84696	84757	84819	84880	84942	85003	85065
71	85126	85187	85248	85309	85370	85431	85491	85552	85612	85673
72	85733	85794	85854	85914	85974	86034	86094	86153	86213	86273
73	86332	86392	86451	86510	86570	86629	86688	86747	86806	86864
74	86923	86982	87040	87099	87157	87216	87274	87332	87390	87448
75	87506	87564	87622	87679	87737	87795	87852	87910	87967	88024
76	88081	88138	88195	88252	88309	88366	88423	88480	88536	88593
77	88649	88705	88762	88818	88874	88930	88986	89042	89098	89154
78	89209	89265	89321	89376	89432	89487	89542	89597	89653	89708
79	89763	89818	89873	89927	89982	90037	90091	90146	90200	90255
80	90309	90363	90417	90472	90526	90580	90634	90687	90741	90795
81	90849	90902	90956	91009	91062	91116	91169	91222	91275	91328
82	91381	91434	91487	91540	91593	91645	91698	91751	91803	91855
83	91908	91960	92012	92065	92117	92169	92221	92273	92324	92376
84	92428	92480	92531	92583	92634	92686	92737	92788	92840	92891
85	92942	92993	93044	93095	93146	93197	93247	93298	93349	93399
86	93450	93500	93551	93601	93651	93702	93752	93802	93852	93902
87	93952	94002	94052	94101	94151	94201	94250	94300	94349	94399
88	94448	94498	94547	94596	94645	94694	94743	94792	94841	94890
89	94939	94988	95036	95085	95134	95182	95231	95279	95328	95376
90	95424	95472	95521	95569	95617	95665	95713	95761	95809	95856
91	95904	95952	95999	96047	96095	96142	96190	96237	96284	96332
92	96379	96426	96473	96520	96567	96614	96661	96708	96755	96802
93	96848	96895	96942	96988	97035	97081	97128	97174	97220	97267
94	97313	97359	97405	97451	97497	97543	97589	97635	97681	97727
95	97772	97818	97864	97909	97955	98000	98046	98091	98137	98182
96	98227	98272	98318	98363	98408	98453	98498	98543	98588	98632
97	98677	98722	98767	98811	98856	98900	98945	98989	99034	99078
98	99123	99167	99211	99255	99300	99344	99388	99432	99476	99520
99	99564	99607	99651	99695	99739	99782	99826	99870	99913	99957
	0	1	2	3	4	5	6	7	8	9

TABLE 61 **Natural Sines**

SINE

Angle	0′	10′	20′	30′	40′	50′	60′	
0°	0.00000	0.00291	0.00582	0.00873	0.01164	0.01454	0.01745	89
1	0.01745	0.02036	0.02327	0.02618	0.02908	0.03199	0.03490	88
2	0.03490	0.03781	0.04071	0.04362	0.04653	0.04943	0.05234	87
3	0.05234	0.05524	0.05814	0.06105	0.06395	0.06685	0.06976	86
4	0.06976	0.07266	0.07556	0.07846	0.08136	0.08426	0.08716	85°
5°	0.08716	0.09005	0.09295	0.09585	0.09874	0.10164	0.10453	84
6	0.10453	0.10742	0.11031	0.11320	0.11609	0.11898	0.12187	83
7	0.12187	0.12476	0.12764	0.13053	0.13341	0.13629	0.13917	82
8	0.13917	0.14205	0.14493	0.14781	0.15069	0.15356	0.15643	81
9	0.15643	0.15931	0.16218	0.16505	0.16792	0.17078	0.17365	80°
10°	0.17365	0.17651	0.17937	0.18224	0.18509	0.18795	0.19081	79
11	0.19081	0.19366	0.19652	0.19937	0.20222	0.20507	0.20791	78
12	0.20791	0.21076	0.21360	0.21644	0.21928	0.22212	0.22495	77
13	0.22495	0.22778	0.23062	0.23345	0.23627	0.23910	0.24192	76
14	0.24192	0.24474	0.24756	0.25038	0.25320	0.25601	0.25882	75°
15°	0.25882	0.26163	0.26443	0.26724	0.27004	0.27284	0.27564	74
16	0.27564	0.27843	0.28123	0.28402	0.28680	0.28959	0.29237	73
17	0.29237	0.29515	0.29793	0.30071	0.30348	0.30625	0.30902	72
18	0.30902	0.31178	0.31454	0.31730	0.32006	0.32282	0.32557	71
19	0.32557	0.32832	0.33106	0.33381	0.33655	0.33929	0.34202	70°
20°	0.34202	0.34475	0.34748	0.35021	0.35293	0.35565	0.35837	69
21	0.35837	0.36108	0.36379	0.36650	0.36921	0.37191	0.37461	68
22	0.37461	0.37730	0.37999	0.38268	0.38537	0.38805	0.39073	67
23	0.39073	0.39341	0.39608	0.39875	0.40142	0.40408	0.40674	66
24	0.40674	0.40939	0.41204	0.41469	0.41734	0.41998	0.42262	65°
25°	0.42262	0.42525	0.42788	0.43051	0.43313	0.43575	0.43837	64
26	0.43837	0.44098	0.44359	0.44620	0.44880	0.45140	0.45399	63
27	0.45399	0.45658	0.45917	0.46175	0.46433	0.46690	0.46947	62
28	0.46947	0.47204	0.47460	0.47716	0.47971	0.48226	0.48481	61
29	0.48481	0.48735	0.48989	0.49242	0.49495	0.49748	0.50000	60°
30°	0.50000	0.50252	0.50503	0.50754	0.51004	0.51254	0.51504	59
31	0.51504	0.51753	0.52002	0.52250	0.52498	0.52745	0.52992	58
32	0.52992	0.53238	0.53484	0.53730	0.53975	0.54220	0.54464	57
33	0.54464	0.54708	0.54951	0.55194	0.55436	0.55678	0.55919	56
34	0.55919	0.56160	0.56401	0.56641	0.56880	0.57119	0.57358	55°
35°	0.57358	0.57596	0.57833	0.58070	0.58307	0.58543	0.58779	54
36	0.58779	0.59014	0.59248	0.59482	0.59716	0.59949	0.60182	53
37	0.60182	0.60414	0.60645	0.60876	0.61107	0.61337	0.61566	52
38	0.61566	0.61795	0.62024	0.62251	0.62479	0.62706	0.62932	51
39	0.62932	0.63158	0.63383	0.63608	0.63832	0.64056	0.64279	50°
40°	0.64279	0.64501	0.64723	0.64945	0.65166	0.65386	0.65606	49
41	0.65606	0.65825	0.66044	0.66262	0.66480	0.66697	0.66913	48
42	0.66913	0.67129	0.67344	0.67559	0.67773	0.67987	0.68200	47
43	0.68200	0.68412	0.68624	0.68835	0.69046	0.69256	0.69466	46
44	0.69466	0.69675	0.69883	0.70091	0.70298	0.70505	0.70711	45
	60′	50′	40′	30′	20′	10′	0′	Angle

COSINE

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and Cosines

SINE

Angle	0′	10′	20′	30′	40′	50′	60′	
45°	0.70711	0.70916	0.71121	0.71325	0.71529	0.71732	0.71934	44
46	0.71934	0.72136	0.72337	0.72537	0.72737	0.72937	0.73135	43
47	0.73135	0.73333	0.73531	0.73728	0.73924	0.74120	0.74314	42
48	0.74314	0.74509	0.74703	0.74896	0.75088	0.75280	0.75471	41
49	0.75471	0.75661	0.75851	0.76041	0.76229	0.76417	0.76604	40°
50°	0.76604	0.76791	0.76977	0.77162	0.77347	0.77531	0.77715	39
51	0.77715	0.77897	0.78079	0.78261	0.78442	0.78622	0.78801	38
52	0.78801	0.78980	0.79158	0.79335	0.79512	0.79688	0.79864	37
53	0.79864	0.80038	0.80212	0.80386	0.80558	0.80730	0.80902	36
54	0.80902	0.81072	0.81242	0.81412	0.81580	0.81748	0.81915	35°
55°	0.81915	0.82082	0.82248	0.82413	0.82577	0.82741	0.82904	34
56	0.82904	0.83066	0.83228	0.83389	0.83549	0.83708	0.83867	33
57	0.83867	0.84025	0.84182	0.84339	0.84495	0.84650	0.84805	32
58	0.84805	0.84959	0.85112	0.85264	0.85416	0.85567	0.85717	31
59	0.85717	0.85866	0.86015	0.86163	0.86310	0.86457	0.86603	30°
60°	0.86603	0.86748	0.86892	0.87036	0.87178	0.87321	0.87462	29
61	0.87462	0.87603	0.87743	0.87882	0.88020	0.88158	0.88295	28
62	0.88295	0.88431	0.88566	0.88701	0.88835	0.88968	0.89101	27
63	0.89101	0.89232	0.89363	0.89493	0.89623	0.89752	0.89879	26
64	0.89879	0.90007	0.90133	0.90259	0.90383	0.90507	0.90631	25°
65°	0.90631	0.90753	0.90875	0.90996	0.91116	0.91236	0.91355	24
66	0.91355	0.91472	0.91590	0.91706	0.91822	0.91936	0.92050	23
67	0.92050	0.92164	0.92276	0.92388	0.92499	0.92609	0.92718	22
68	0.92718	0.92827	0.92935	0.93042	0.93148	0.93253	0.93358	21
69	0.93358	0.93462	0.93565	0.93667	0.93769	0.93869	0.93969	20°
70°	0.93969	0.94068	0.94167	0.94264	0.94361	0.94457	0.94552	19
71	0.94552	0.94646	0.94740	0.94832	0.94924	0.95015	0.95106	18
72	0.95106	0.95195	0.95284	0.95372	0.95459	0.95545	0.95630	17
73	0.95630	0.95715	0.95799	0.95882	0.95964	0.96046	0.96126	16
74	0.96126	0.96206	0.96285	0.96363	0.96440	0.96517	0.96593	15°
75°	0.96593	0.96667	0.96742	0.96815	0.96887	0.96959	0.97030	14
76	0.97030	0.97100	0.97169	0.97237	0.97304	0.97371	0.97437	13
77	0.97437	0.97502	0.97566	0.97630	0.97692	0.97754	0.97815	12
78	0.97815	0.97875	0.97934	0.97992	0.98050	0.98107	0.98163	11
79	0.98163	0.98218	0.98272	0.98325	0.98378	0.98430	0.98481	10°
80°	0.98481	0.98531	0.98580	0.98629	0.98676	0.98723	0.98769	9
81	0.98769	0.98814	0.98858	0.98902	0.98944	0.98986	0.99027	8
82	0.99027	0.99067	0.99106	0.99144	0.99182	0.99219	0.99255	7
83	0.99255	0.99290	0.99324	0.99357	0.99390	0.99421	0.99452	6
84	0.99452	0.99482	0.99511	0.99540	0.99567	0.99594	0.99619	5°
85°	0.99619	0.99644	0.99668	0.99692	0.99714	0.99736	0.99756	4
86	0.99756	0.99776	0.99795	0.99813	0.99831	0.99847	0.99863	3
87	0.99863	0.99878	0.99892	0.99905	0.99917	0.99929	0.99939	2
88	0.99939	0.99949	0.99958	0.99966	0.99973	0.99979	0.99985	1
89	0.99985	0.99989	0.99993	0.99996	0.99998	1.00000	1.00000	0°
	60′	50′	40′	30′	20′	10′	0′	Angle

COSINE

TABLE 62 TANGENT

Natural Tangents

Angle	0′	10′	20′	30′	40′	50′	60′	
0°	0.00000	0.00291	0.00582	0.00873	0.01164	0.01455	0.01746	89
1	0.01746	0.02036	0.02328	0.02619	0.02910	0.03201	0.03492	88
2	0.03492	0.03783	0.04075	0.04366	0.04658	0.04949	0.05241	87
3	0.05241	0.05533	0.05824	0.06116	0.06408	0.06700	0.06993	86
4	0.06993	0.07285	0.07578	0.07870	0.08163	0.08456	0.08749	85°
5°	0.08749	0.09042	0.09335	0.09629	0.09923	0.10216	0.10510	84
6	0.10510	0.10805	0.11099	0.11394	0.11688	0.11983	0.12278	83
7	0.12278	0.12574	0.12869	0.13165	0.13461	0.13758	0.14054	82
8	0.14054	0.14351	0.14648	0.14945	0.15243	0.15540	0.15838	81
9	0.15838	0.16137	0.16435	0.16734	0.17033	0.17333	0.17633	80°
10°	0.17633	0.17933	0.18233	0.18534	0.18835	0.19136	0.19438	79
11	0.19438	0.19740	0.20042	0.20345	0.20648	0.20952	0.21256	78
12	0.21256	0.21560	0.21864	0.22169	0.22475	0.22781	0.23087	77
13	0.23087	0.23393	0.23700	0.24008	0.24316	0.24624	0.24933	76
14	0.24933	0.25242	0.25552	0.25862	0.26172	0.26483	0.26795	75°
15°	0.26795	0.27107	0.27419	0.27732	0.28046	0.28360	0.28675	74
16	0.28675	0.28990	0.29305	0.29621	0.29938	0.30255	0.30573	73
17	0.30573	0.30891	0.31210	0.31530	0.31850	0.32171	0.32492	72
18	0.32492	0.32814	0.33136	0.33460	0.33783	0.34108	0.34433	71
19	0.34433	0.34758	0.35085	0.35412	0.35740	0.36068	0.36397	70°
20°	0.36397	0.36727	0.37057	0.37388	0.37720	0.38053	0.38386	69
21	0.38386	0.38721	0.39055	0.39391	0.39727	0.40065	0.40403	68
22	0.40403	0.40741	0.41081	0.41421	0.41763	0.42105	0.42447	67
23	0.42447	0.42791	0.43136	0.43481	0.43828	0.44175	0.44523	66
24	0.44523	0.44872	0.45222	0.45573	0.45924	0.46277	0.46631	65°
25°	0.46631	0.46985	0.47341	0.47698	0.48055	0.48414	0.48773	64
26	0.48773	0.49134	0.49495	0.49858	0.50222	0.50587	0.50953	63
27	0.50953	0.51320	0.51688	0.52057	0.52427	0.52798	0.53171	62
28	0.53171	0.53545	0.53920	0.54296	0.54673	0.55051	0.55431	61
29	0.55431	0.55812	0.56194	0.56577	0.56962	0.57348	0.57735	60°
30°	0.57735	0.58124	0.58513	0.58905	0.59297	0.59691	0.60086	59
31	0.60086	0.60483	0.60881	0.61280	0.61681	0.62083	0.62487	58
32	0.62487	0.62892	0.63299	0.63707	0.64117	0.64528	0.64941	57
33	0.64941	0.65355	0.65771	0.66189	0.66608	0.67028	0.67451	56
34	0.67451	0.67875	0.68301	0.68728	0.69157	0.69588	0.70021	55°
35°	0.70021	0.70455	0.70891	0.71329	0.71769	0.72211	0.72654	54
36	0.72654	0.73100	0.73547	0.73996	0.74447	0.74900	0.75355	53
37	0.75355	0.75812	0.76272	0.76733	0.77196	0.77661	0.78129	52
38	0.78129	0.78598	0.79070	0.79544	0.80020	0.80498	0.80978	51
39	0.80978	0.81461	0.81946	0.82434	0.82923	0.83415	0.83910	50°
40°	0.83910	0.84407	0.84906	0.85408	0.85912	0.86419	0.86929	49
41	0.86929	0.87441	0.87955	0.88473	0.88992	0.89515	0.90040	48
42	0.90040	0.90569	0.91099	0.91633	0.92170	0.92709	0.93252	47
43	0.93252	0.93797	0.94345	0.94896	0.95451	0.96008	0.96569	46
44	0.96569	0.97133	0.97700	0.98270	0.98843	0.99420	1.00000	45°
	60′	50′	40′	30′	20′	10′	0′	Angle

COTANGENT

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and Cotangents

TANGENT

Angle	0′	10′	20′	30′	40′	50′	60′	
45°	1.00000	1.00583	1.01170	1.01761	1.02355	1.02952	1.03553	44
46	1.03553	1.04158	1.04766	1.05378	1.05994	1.06613	1.07237	43
47	1.07237	1.07864	1.08496	1.09131	1.09770	1.10414	1.11061	42
48	1.11061	1.11713	1.12369	1.13029	1.13694	1.14363	1.15037	41
49	1.15037	1.15715	1.16398	1.17085	1.17777	1.18474	1.19175	40°
50°	1.19175	1.19882	1.20593	1.21310	1.22031	1.22758	1.23490	39
51	1.23490	1.24227	1.24969	1.25717	1.26471	1.27230	1.27994	38
52	1.27994	1.28764	1.29541	1.30323	1.31110	1.31904	1.32704	37
53	1.32704	1.33511	1.34323	1.35142	1.35968	1.36800	1.37638	36
54	1.37638	1.38484	1.39336	1.40195	1.41061	1.41934	1.42815	35°
55°	1.42815	1.43703	1.44598	1.45501	1.46411	1.47330	1.48256	34
56	1.48256	1.49190	1.50133	1.51084	1.52043	1.53010	1.53987	33
57	1.53987	1.54972	1.55966	1.56969	1.57981	1.59002	1.60033	32
58	1.60033	1.61074	1.62125	1.63185	1.64256	1.65337	1.66428	31
59	1.66428	1.67530	1.68643	1.69766	1.70901	1.72047	1.73205	30°
60°	1.73205	1.74375	1.75556	1.76749	1.77955	1.79174	1.80405	29
61	1.80405	1.81649	1.82906	1.84177	1.85462	1.86760	1.88073	28
62	1.88073	1.89400	1.90741	1.92098	1.93470	1.94858	1.96261	27
63	1.96261	1.97680	1.99116	2.00569	2.02039	2.03526	2.05030	26
64	2.05030	2.06553	2.08094	2.09654	2.11233	2.12832	2.14451	25°
65°	2.14451	2.16090	2.17749	2.19430	2.21132	2.22857	2.24604	24
66	2.24604	2.26374	2.28167	2.29984	2.31826	2.33693	2.35585	23
67	2.35585	2.37504	2.39449	2.41421	2.43422	2.45451	2.47509	22
68	2.47509	2.49597	2.51715	2.53865	2.56046	2.58261	2.60509	21
69	2.60509	2.62791	2.65109	2.67462	2.69853	2.72281	2.74748	20°
70°	2.74748	2.77254	2.79802	2.82391	2.85023	2.87700	2.90421	19
71	2.90421	2.93189	2.96004	2.98869	3.01783	3.04749	3.07768	18
72	3.07768	3.10842	3.13972	3.17159	3.20406	3.23714	3.27085	17
73	3.27085	3.30521	3.34023	3.37594	3.41236	3.44951	3.48741	16
74	3.48741	3.52609	3.56557	3.60588	3.64705	3.68909	3.73205	15°
75°	3.73205	3.77595	3.82083	3.86671	3.91364	3.96165	4.01078	14
76	4.01078	4.06107	4.11256	4.16530	4.21933	4.27471	4.33148	13
77	4.33148	4.38969	4.44942	4.51071	4.57363	4.63825	4.70463	12
78	4.70463	4.77286	4.84300	4.91516	4.98940	5.06584	5.14455	11
79	5.14455	5.22566	5.30928	5.39552	5.48451	5.57638	5.67128	10°
80°	5.67128	5.76937	5.87080	5.97576	6.08444	6.19703	6.31375	9
81	6.31375	6.43484	6.56055	6.69116	6.82694	6.96823	7.11537	8
82	7.11537	7.26873	7.42871	7.59575	7.77035	7.95302	8.14435	7
83	8.14435	8.34496	8.55555	8.77689	9.00983	9.25530	9.51436	6
84	9.51436	9.78817	10.0780	10.3854	10.7119	11.0594	11.4301	5°
85°	11.4301	11.8262	12.2505	12.7062	13.1969	13.7267	14.3007	4
86	14.3007	14.9244	15.6048	16.3499	17.1693	18.0750	19.0811	3
87	19.0811	20.2056	21.4704	22.9038	24.5418	26.4316	28.6363	2
88	28.6363	31.2416	34.3678	38.1885	42.9641	49.1039	57.2900	1
89	57.2900	68.7501	85.9398	114.589	171.885	343.774	∞	0°
	60′	50′	40′	30′	20′	10′	0′	Angle

COTANGENT

TABLE 63

THREE-HALVES POWERS OF NUMBERS

No.	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
0.00	.0000	.0001	.0002	.0003	.0004	.0005	.0006	.0007	.0008	.0009
.01	.0010	.0012	.0014	.0015	.0017	.0019	.0021	.0022	.0024	.0026
.02	.0028	.0030	.0033	.0035	.0038	.0040	.0042	.0045	.0047	.0050
.03	.0052	.0055	.0058	.0060	.0063	.0066	.0069	.0072	.0074	.0077
.04	.0080	.0083	.0086	.0090	.0093	.0096	.0099	.0102	.0106	.0109
.05	.0112	.0116	.0119	.0122	.0126	.0130	.0133	.0136	.0140	.0144
.06	.0147	.0151	.0155	.0158	.0162	.0166	.0170	.0174	.0177	.0181
.07	.0185	.0189	.0193	.0197	.0201	.0206	.0210	.0214	.0218	.0222
.08	.0226	.0230	.0235	.0239	.0244	.0248	.0252	.0257	.0261	.0266
.09	.0270	.0275	.0279	.0284	.0288	.0293	.0298	.0302	.0307	.0311
.10	.0316	.0321	.0326	.0331	.0336	.0340	.0345	.0350	.0355	.0360
.11	.0365	.0370	.0375	.0380	.0385	.0390	.0396	.0401	.0406	.0411
.12	.0416	.0421	.0427	.0432	.0437	.0442	.0448	.0453	.0458	.0464
.13	.0469	.0474	.0480	.0486	.0491	.0496	.0502	.0508	.0513	.0518
.14	.0524	.0530	.0535	.0541	.0547	.0552	.0558	.0564	.0570	.0575
.15	.0581	.0587	.0593	.0599	.0605	.0610	.0616	.0622	.0628	.0634
.16	.0640	.0645	.0652	.0658	.0664	.0670	.0677	.0683	.0689	.0695
.17	.0701	.0707	.0714	.0720	.0726	.0732	.0739	.0745	.0751	.0758
.18	.0764	.0770	.0777	.0783	.0790	.0796	.0802	.0809	.0815	.0822
.19	.0828	.0835	.0841	.0848	.0854	.0861	.0868	.0874	.0881	.0887
.20	.0894	.0901	.0908	.0914	.0921	.0928	.0935	.0942	.0948	.0955
.21	.0962	.0969	.0976	.0983	.0990	.0997	.1004	.1011	.1018	.1025
.22	.1032	.1039	.1046	.1053	.1060	.1068	.1075	.1082	.1089	.1096
.23	.1103	.1110	.1118	.1125	.1132	.1140	.1147	.1154	.1161	.1169
.24	.1176	.1183	.1191	.1198	.1251	.1213	.1220	.1228	.1235	.1243
.25	.1250	.1258	.1265	.1273	.1280	.1288	.1296	.1303	.1311	.1318
.26	.1326	.1334	.1341	.1349	.1357	.1364	.1372	.1380	.1388	.1395
.27	.1403	.1411	.1419	.1427	.1435	.1442	.1450	.1458	.1466	.1474
.28	.1482	.1490	.1498	.1506	.1514	.1522	.1530	.1538	.1546	.1554
.29	.1562	.1570	.1578	.1586	.1594	.1602	.1611	.1619	.1627	.1635
.30	.1643	.1651	.1660	.1668	.1676	.1684	.1693	.1701	.1709	.1718
.31	.1726	.1734	.1743	.1751	.1760	.1768	.1776	.1785	.1793	.1802
.32	.1810	.1819	.1827	.1836	.1844	.1853	.1862	.1870	.1879	.1887
.33	.1896	.1905	.1913	.1922	.1931	.1940	.1948	.1957	.1966	.1974
.34	.1983	.1992	.2001	.2009	.2018	.2027	.2036	.2045	.2053	.2062
.35	.2071	.2080	.2089	.2098	.2107	.2116	.2124	.2133	.2142	.2151
.36	.2160	.2169	.2178	.2187	.2196	.2206	.2215	.2224	.2233	.2242
.37	.2251	.2260	.2269	.2278	.2287	.2296	.2306	.2315	.2324	.2333
.38	.2342	.2351	.2361	.2370	.2380	.2389	.2398	.2408	.2417	.2427
.39	.2436	.2445	.2455	.2464	.2474	.2483	.2492	.2502	.2511	.2521
.40	.2530	.2540	.2549	.2558	.2568	.2578	.2587	.2596	.2606	.2616
.41	.2625	.2635	.2644	.2654	.2664	.2674	.2683	.2693	.2703	.2712
.42	.2722	.2732	.2742	.2751	.2761	.2771	.2781	.2791	.2800	.2810
.43	.2820	.2830	.2840	.2850	.2860	.2870	.2879	.2889	.2899	.2909
.44	.2919	.2929	.2939	.2049	.2959	.2969	.2979	.2989	.2999	.3009
.45	.3019	.3029	.3039	.3049	.3059	.3070	.3080	.3090	.3100	.3110
.46	.3120	.3130	.3140	.3151	.3161	.3171	.3181	.3191	.3202	.3212
.47	.3222	.3232	.3243	.3253	.3263	.3274	.3284	.3294	.3304	.3315
.48	.3325	.3336	.3346	.3356	.3367	.3378	.3388	.3398	.3409	.3420
.49	.3430	.3441	.3451	.3462	.3472	.3483	.3494	.3504	.3515	.3525

TABLE 63 (*Continued*)

THREE-HALVES POWERS OF NUMBERS

No.	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
0.50	.3536	.3547	.3557	.3568	.3578	.3589	.3600	.3610	.3621	.3631
.51	.3642	.3653	.3664	.3674	.3685	.3696	.3707	.3718	.3728	.3739
.52	.3750	.3761	.3772	.3782	.3793	.3804	.3815	.3826	.3836	.3847
.53	.3858	.3869	.3880	.3891	.3902	.3913	.3924	.3935	.3946	.3957
.54	.3968	.3979	.3990	.4001	.4012	.4024	.4035	.4046	.4057	.4068
.55	.4079	.4090	.4101	.4113	.4124	.4135	.4146	.4157	.4169	.4180
.56	.4191	.4202	.4213	.4225	.4236	.4247	.4258	.4269	.4281	.4292
.57	.4303	.4314	.4326	4337	.4349	.4360	.4371	.4383	.4394	.4406
.58	.4417	.4428	.4440	.4452	.4463	.4474	.4486	.4498	.4509	.4520
.59	.4532	.4544	.4555	.4567	.4578	.4590	.4602	.4613	.4625	.4636
.60	.4648	.4660	.4671	.4683	.4694	.4706	.4718	.4729	.4741	.4752
.61	.4764	.4776	.4788	.4799	.4811	.4823	.4835	.4847	.4858	.4870
.62	.4882	.4894	.4906	.4917	.4929	.4941	.4953	.4965	.4976	.4988
.63	.5000	.5012	.5024	.5036	.5048	.5060	.5072	.5084	.5096	.5108
.64	.5120	.5132	.5144	.5156	.5168	.5180	.5192	.5204	.5216	.5228
.65	.5240	.5252	.5264	.5277	.5289	.5301	.5313	.5325	.5338	.5350
.66	.5362	.5374	.5386	.5399	.5411	.5423	.5435	.5447	.5460	.5472
.67	.5484	.5496	.5509	.5521	.5533	.5546	.5558	.5570	.5582	.5595
.68	.5607	.5620	.5632	.5644	.5657	.5670	.5682	.5694	.5707	.5720
.69	.5732	.5744	.5757	.5770	.5782	.5794	.5807	.5820	.5832	.5844
.70	.5857	.5870	.5882	.5895	.5907	.5920	.5933	.5945	.5958	.5970
.71	.5983	.5996	.6008	.6021	.6033	.6046	.6059	.6071	.6084	.6096
.72	.6109	.6122	.6135	.6147	.6160	.6173	.6186	.6199	.6211	.6224
.73	.6237	.6250	.6263	.6276	.6289	.6302	.6314	.6327	.6340	.6353
.74	.6366	.6379	.6392	.6405	.6418	.6430	.6443	.6456	.6469	.6482
.75	.6495	.6508	.6521	.6534	.6547	.6560	.6574	.6587	.6600	.6613
.76	.6626	.6639	.6652	.6665	.6678	.6692	.6705	.6718	.6731	.6744
.77	.6757	.6770	.6783	.6797	.6810	.6823	.6836	.6849	.6863	.6876
.78	.6889	.6902	.6916	.6929	.6942	.6956	.6969	.6982	.6995	.7009
.79	.7022	.7035	.7049	.7062	.7075	.7088	.7102	.7115	.7128	.7142
.80	.7155	.7168	.7182	.7196	.7209	.7222	.7236	.7250	.7263	.7276
.81	.7290	.7304	.7317	.7330	.7344	.7358	.7371	.7384	.7398	.7412
.82	.7425	.7439	.7452	.7466	.7480	.7494	.7507	.7521	.7535	.7548
.83	.7562	.7576	.7589	.7603	.7617	.7630	.7644	.7658	.7672	.7685
.84	.7699	.7713	.7727	.7740	.7754	.7768	.7782	.7796	.7809	.7823
.85	.7837	.7851	.7865	.7878	.7892	.7906	.7920	.7934	.7947	.7961
.86	.7975	.7989	.8003	.8017	.8031	.8045	.8059	.8073	.8087	.8101
.87	.8115	.8129	.8143	.8157	.8171	.8185	.8199	.8213	.8227	.8241
.88	.8255	.8269	.8283	.8297	.8311	.8326	.8340	.8354	.8368	.8382
.89	.8396	.8410	.8424	.8439	.8453	.8467	.8481	.8495	.8510	.8524
.90	.8538	.8552	.8567	.8581	.8595	.8610	.8624	.8638	.8652	.8667
.91	.8681	.8695	.8710	.8724	.8738	.8752	.8767	.8781	.8795	.8810
.92	.8824	.8838	.8853	.8868	.8882	.8896	.8911	.8926	.8940	.8954
.93	.8969	.8984	.8998	.9012	.9027	.9042	.9056	.9070	.9085	.9100
.94	.9114	.9128	.9143	.9158	.9172	.9186	.9201	.9216	.9230	.9244
.95	.9259	.9274	.9288	.9302	.9317	.9332	.9347	.9362	.9377	.9391
.96	.9406	.9421	.9435	.9450	.9465	.9480	.9494	.9509	.9524	.9538
.97	.9553	.9568	.9583	.9598	.9613	.9628	.9642	.9657	.9672	.9687
.98	.9702	.9717	.9732	.9746	.9761	.9776	.9791	.9806	.9820	.9835
.99	.9850	.9865	.9880	.9895	.9910	.9925	.9940	.9955	.9970	.9985

TABLE 63 (*Continued*)

THREE-HALVES POWERS OF NUMBERS

No.	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
1.00	1.0000	1.0015	1.0030	1.0045	1.0060	1.0075	1.0090	1.0105	1.0120	1.0135
1.01	1.0150	1.0165	1.0180	1.0196	1.0211	1.0226	1.0241	1.0256	1.0272	1.0287
1.02	1.0302	1.0317	1.0332	1.0347	1.0362	1.0378	1.0393	1.0408	1.0428	1.0438
1.03	1.0453	1.0468	1.0484	1.0499	1.0514	1.0530	1.0545	1.0560	1.0575	1.0591
1.04	1.0606	1.0621	1.0637	1.0652	1.0667	1.0682	1.0698	1.0713	1.0728	1.0744
1.05	1.0759	1.0774	1.0790	1.0805	1.0821	1.0836	1.0851	1.0867	1.0882	1.0898
1.06	1.0913	1.0928	1.0944	1.0960	1.0975	1.0990	1.1006	1.1022	1.1037	1.1052
1.07	1.1068	1.1084	1.1099	1.1115	1.1130	1.1146	1.1162	1.1177	1.1193	1.1208
1.08	1.1224	1.1240	1.1255	1.1271	1.1286	1.1302	1.1318	1.1333	1.1349	1.1364
1.09	1.1380	1.1396	1.1411	1.1427	1.1443	1.1458	1.1474	1.1490	1.1506	1.1521
1.10	1.1537	1.1553	1.1569	1.1584	1.1600	1.1616	1.1632	1.1648	1.1663	1.1679
1.11	1.1695	1.1711	1.1727	1.1742	1.1758	1.1774	1.1790	1.1806	1.1821	1.1837
1.12	1.1853	1.1869	1.1885	1.1901	1.1917	1.1932	1.1948	1.1964	1.1980	1.1996
1.13	1.2012	1.2028	1.2044	1.2060	1.2076	1.2092	1.2108	1.2124	1.2140	1.2156
1.14	1.2172	1.2188	1.2204	1.2220	1.2236	1.2252	1.2268	1.2284	1.2300	1.2316
1.15	1.2332	1.2348	1.2364	1.2381	1.2397	1.2413	1.2429	1.2445	1.2462	1.2478
1.16	1.2494	1.2510	1.2526	1.2543	1.2559	1.2575	1.2591	1.2607	1.2624	1.2640
1.17	1.2656	1.2672	1.2688	1.2705	1.2721	1.2737	1.2753	1.2769	1.2786	1.2802
1.18	1.2818	1.2834	1.2851	1.2867	1.2883	1.2900	1.2916	1.2932	1.2948	1.2965
1.19	1.2981	1.2997	1.3014	1.3030	1.3047	1.3063	1.3079	1.3096	1.3112	1.3129
1.20	1.3145	1.3162	1.3178	1.3194	1.3211	1.3228	1.3244	1.3260	1.3277	1.3294
1.21	1.3310	1.3326	1.3343	1.3360	1.3376	1.3392	1.3409	1.3426	1.3442	1.3458
1.22	1.3475	1.3492	1.3508	1.3525	1.3541	1.3558	1.3575	1.3591	1.3608	1.3624
1.23	1.3641	1.3658	1.3674	1.3691	1.3768	1.3724	1.3741	1.3758	1.3775	1.3791
1.24	1.3808	1.3825	1.3841	1.3858	1.3875	1.3892	1.3908	1.3925	1.3942	1.3958
1.25	1.3975	1.3992	1.4009	1.4026	1.4043	1.4060	1.4076	1.4093	1.4110	1.4127
1.26	1.4144	1.4161	1.4178	1.4194	1.4211	1.4228	1.4245	1.4262	1.4278	1.4295
1.27	1.4312	1.4329	1.4346	1.4363	1.4380	1.4397	1.4414	1.4431	1.4448	1.4465
1.28	1.4482	1.4499	1.4516	1.4533	1.4550	1.4567	1.4584	1.4601	1.4618	1.4635
1.29	1.4652	1.4669	1.4686	1.4703	1.4720	1.4737	1.4754	1.4771	1.4788	1.4805
1.30	1.4822	1.4839	1.4856	1.4874	1.4891	1.4908	1.4925	1.4942	1.4960	1.4977
1.31	1.4994	1.5011	1.5028	1.5046	1.5063	1.5080	1.5097	1.5114	1.5132	1.5149
1.32	1.5166	1.5183	1.5200	1.5218	1.5235	1.5252	1.5269	1.5286	1.5304	1.5321
1.33	1.5338	1.5355	1.5373	1.5390	1.5408	1.5425	1.5442	1.5460	1.5477	1.5495
1.34	1.5512	1.5529	1.5547	1.5564	1.5582	1.5599	1.5616	1.5634	1.5651	1.5669
1.35	1.5686	1.5703	1.5721	1.5738	1.5756	1.5773	1.5790	1.5808	1.5825	1.5843
1.36	1.5860	1.5878	1.5895	1.5912	1.5930	1.5948	1.5965	1.5982	1.6000	1.6018
1.37	1.6035	1.6053	1.6070	1.6088	1.6105	1.6123	1.6141	1.6158	1.6176	1.6193
1.38	1.6211	1.6229	1.6246	1.6264	1.6282	1.6300	1.6317	1.6335	1.6353	1.6370
1.39	1.6388	1.6406	1.6423	1.6441	1.6459	1.6476	1.6494	1.6512	1.6530	1.6547
1.40	1.6565	1.6583	1.6601	1.6618	1.6636	1.6654	1.6672	1.6690	1.6708	1.6725
1.41	1.6743	1.6761	1.6779	1.6796	1.6814	1.6832	1.6850	1.6868	1.6885	1.6903
1.42	1.6921	1.6939	1.6957	1.6975	1.6993	1.7010	1.7028	1.7046	1.7064	1.7082
1.43	1.7100	1.7118	1.7136	1.7154	1.7172	1.7190	1.7208	1.7226	1.7244	1.7262
1.44	1.7280	1.7298	1.7316	1.7334	1.7352	1.7370	1.7388	1.7406	1.7424	1.7442
1.45	1.7460	1.7478	1.7496	1.7514	1.7532	1.7550	1.7569	1.7587	1.7605	1.7623
1.46	1.7641	1.7659	1.7677	1.7696	1.7714	1.7732	1.7750	1.7768	1.7787	1.7805
1.47	1.7823	1.7841	1.7859	1.7878	1.7896	1.7914	1.7932	1.7950	1.7969	1.7987
1.48	1.8005	1.8023	1.8042	1.8060	1.8078	1.8096	1.8115	1.8133	1.8151	1.8170
1.49	1.8188	1.8206	1.8225	1.8243	1.8261	1.8280	1.8298	1.8316	1.8334	1.8353

TABLE 63 (*Continued*)

THREE-HALVES POWERS OF NUMBERS

No.	.00	01	.02	.03	.04	.05	.06	.07	.08	.09
1.5	1.838	1.856	1.874	1.892	1.911	1.930	1.948	1.967	1.986	2.005
1.6	2.024	2.043	2.062	2.081	2.100	2.120	2.139	2.158	2.178	2.197
1.7	2.216	2.236	2.256	2.276	2.295	2.315	2.335	2.355	2.375	2.395
1.8	2.415	2.435	2.455	2.476	2.496	2.516	2.537	2.557	2.578	2.598
1.9	2.619	2.640	2.660	2.681	2.702	2.723	2.744	2.765	2.786	2.807
2.0	2.828	2.850	2.871	2.892	2.914	2.935	2.957	2.978	3.000	3.022
2.1	3.043	3.065	3.087	3.109	3.131	3.152	3.174	3.197	3.219	3.241
2.2	3.263	3.285	3.308	3.330	3.352	3.375	3.398	3.420	3.443	3.465
2.3	3.488	3.511	3.534	3.557	3.580	3.602	3.626	3.649	3.672	3.695
2.4	3.718	3.741	3.765	3.788	3.811	3.835	3.858	3.882	3.906	3.929
2.5	3.953	3.977	4.000	4.024	4.048	4.072	4.096	4.120	4.144	4.168
2.6	4.192	4.217	4.241	4.265	4.290	4.314	4.338	4.363	4.387	4.412
2.7	4.437	4.461	4.486	4.511	4.536	4.560	4.585	4.610	4.635	4.660
2.8	4.685	4.710	4.736	4.761	4.786	4.811	4.837	4.862	4.888	4.913
2.9	4.938	4.964	4.990	5.015	5.041	5.067	5.093	5.118	5.144	5.170
3.0	5.196	5.222	5.248	5.274	5.300	5.327	5.353	5.379	5.405	5.432
3.1	5.458	5.484	5.511	5.538	5.564	5.591	5.617	5.644	5.671	5.698
3.2	5.724	5.751	5.778	5.805	5.832	5.859	5.886	5.913	5.940	5.968
3.3	5.995	6.022	6.049	6.077	6.104	6.132	6.159	6.186	6.214	6.242
3.4	6.269	6.297	6.325	6.352	6.380	6.408	6.436	6.464	6.492	6.520
3.5	6.548	6.576	6.604	6.632	6.660	6.689	6.717	6.745	6.774	6.802
3.6	6.830	6.859	6.888	6.916	6.945	6.973	7.002	7.031	7.060	7.088
3.7	7.117	7.146	7.175	7.204	7.233	7.262	7.291	7.320	7.349	7.378
3.8	7.408	7.437	7.466	7.496	7.525	7.554	7.584	7.613	7.643	7.672
3.9	7.702	7.732	7.770	7.791	7.821	7.850	7.880	7.910	7.940	7.970
4.0	8.000	8.030	8.060	8.090	8.120	8.150	8.181	8.211	8.241	8.272
4.1	8.302	8.332	8.363	8.393	8.424	8.454	8.485	8.515	8.546	8.577
4.2	8.607	8.638	8.669	8.700	8.731	8.762	8.792	8.824	8.854	8.886
4.3	8.917	8.948	8.979	9.010	9.041	9.073	9.104	9.135	9.167	9.198
4.4	9.230	9.261	9.292	9.324	9.356	9.387	9.419	9.451	9.482	9.514
4.5	9.546	9.578	9.610	9.642	9.674	9.706	9.738	9.770	9.802	9.834
4.6	9.866	9.898	9.930	9.963	9.995	10.03	10.06	10.09	10.12	10.16
4.7	10.19	10.22	10.25	10.29	10.32	10.35	10.39	10.42	10.45	10.48
4.8	10.52	10.55	10.58	10.62	10.65	10.68	10.71	10.75	10.78	10.81
4.9	10.85	10.88	10.91	10.95	10.98	11.01	11.05	11.08	11.11	11.15
5.0	11.18	11.21	11.25	11.28	11.31	11.35	11.38	11.42	11.45	11.48
5.1	11.52	11.55	11.59	11.62	11.65	11.69	11.72	11.76	11.79	11.82
5.2	11.86	11.89	11.93	11.96	11.99	12.03	12.06	12.10	12.13	12.17
5.3	12.20	12.24	12.27	12.31	12.34	12.37	12.41	12.44	12.48	12.51
5.4	12.55	12.58	12.62	12.65	12.69	12.72	12.76	12.79	12.83	12.86
5.5	12.90	12.93	12.97	13.00	13.04	13.07	13.11	13.15	13.18	13.22
5.6	13.25	13.29	13.32	13.36	13.39	13.43	13.47	13.50	13.54	13.57
5.7	13.61	13.64	13.68	13.72	13.75	13.79	13.82	13.86	13.90	13.93
5.8	13.97	14.00	14.04	14.08	14.11	14.15	14.19	14.22	14.26	14.29
5.9	14.33	14.37	14.40	14.44	14.48	14.51	14.55	14.59	14.62	14.66
6.0	14.70	14.73	14.77	14.81	14.84	14.88	14.92	14.95	14.99	15.03
6.1	15.07	15.10	15.14	15.18	15.21	15.25	15.29	15.33	15.36	15.40
6.2	15.44	15.48	15.51	15.55	15.59	15.62	15.66	15.70	15.74	15.78
6.3	15.81	15.85	15.89	15.93	15.96	16.00	16.04	16.08	16.12	16.15
6.4	16.19	16.23	16.27	16.30	16.34	16.38	16.42	16.46	16.50	16.53

TABLE 63 (*Concluded*)

THREE-HALVES POWERS OF NUMBERS

No.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
6.5	16.57	16.61	16.65	16.69	16.72	16.76	16.80	16.84	16.88	16.92
6.6	16.96	16.99	17.03	17.07	17.11	17.15	17.19	17.22	17.26	17.30
6.7	17.34	17.38	17.42	17.46	17.50	17.54	17.58	17.62	17.65	17.69
6.8	17.73	17.77	17.81	17.85	17.89	17.93	17.97	18.01	18.05	18.09
6.9	18.12	18.16	18.20	18.24	18.28	18.32	18.36	18.40	18.44	18.48
7.0	18.52	18.56	18.60	18.64	18.68	18.72	18.76	18.80	18.84	18.88
7.1	18.92	18.96	19.00	19.04	19.08	19.12	19.16	19.20	19.24	19.28
7.2	19.32	19.36	19.40	19.44	19.48	19.52	19.56	19.60	19.64	19.68
7.3	19.72	19.76	19.80	19.85	19.89	19.93	19.97	20.01	20.05	20.09
7.4	20.13	20.17	20.21	20.25	20.29	20.33	20.38	20.42	20.46	20.50
7.5	20.54	20.58	20.62	20.66	20.70	20.75	20.79	20.83	20.87	20.91
7.6	20.95	20.99	21.03	21.08	21.12	21.16	21.20	21.24	21.28	21.32
7.7	21.37	21.41	21.45	21.49	21.53	21.58	21.62	21.66	21.70	21.74
7.8	21.78	21.83	21.87	21.91	21.95	21.99	22.04	22.08	22.12	22.16
7.9	22.20	22.25	22.29	22.33	22.37	22.42	22.46	22.50	22.54	22.58
8.0	22.63	22.67	22.71	22.75	22.80	22.84	22.88	22.93	22.97	23.01
8.1	23.05	23.10	23.14	23.18	23.22	23.27	23.31	23.35	23.40	23.44
8.2	23.48	23.52	23.57	23.61	23.65	23.70	23.74	23.78	23.83	23.87
8.3	23.91	23.96	24.00	24.04	24.09	24.13	24.17	24.22	24.26	24.30
8.4	24.35	24.39	24.43	24.48	24.52	24.56	24.61	24.65	24.69	24.74
8.5	24.78	24.83	24.87	24.91	24.96	25.00	25.04	25.09	25.13	25.18
8.6	25.22	25.26	25.31	25.35	25.40	25.44	25.48	25.53	25.57	25.62
8.7	25.66	25.71	25.75	25.79	25.84	25.88	25.93	25.97	26.02	26.06
8.8	26.10	26.15	26.19	26.24	26.28	26.33	26.37	26.42	26.46	26.51
8.9	26.55	26.60	26.64	26.69	26.73	26.78	26.82	26.87	26.91	26.96
9.0	27.00	27.04	27.09	27.14	27.18	27.23	27.27	27.32	27.36	27.41
9.1	27.45	27.50	27.54	27.59	27.63	27.68	27.72	27.77	27.81	27.86
9.2	27.90	27.95	28.00	28.04	28.09	28.13	28.18	28.22	28.27	28.32
9.3	28.36	28.41	28.45	28.50	28.54	28.59	28.64	28.68	28.73	28.77
9.4	28.82	28.87	28.91	28.96	29.00	29.05	29.10	29.14	29.19	29.23
9.5	29.28	29.33	29.37	29.42	29.47	29.51	29.56	29.61	29.65	29.70
9.6	29.74	29.79	29.84	29.88	29.93	29.98	30.02	30.07	30.12	30.16
9.7	30.21	30.26	30.30	30.35	30.40	30.44	30.49	30.54	30.58	30.63
9.8	30.68	30.73	30.77	30.82	30.87	30.91	30.96	31.01	31.06	31.10
9.9	31.15	31.20	31.24	31.29	31.34	31.38	31.43	31.48	31.53	31.58
10.0	31.62	31.67	31.72	31.77	31.81	31.86	31.91	31.96	32.00	32.05

TABLE 64

CONVENTIONAL SIGNS FOR IRRIGATION STRUCTURES

Adopted by U. S. Reclamation Service

Dam

Diversion dam or weir

Headworks

Tunnel

Bridge

Spillway

Drainage culvert under canal

Box or pipe culvert under road

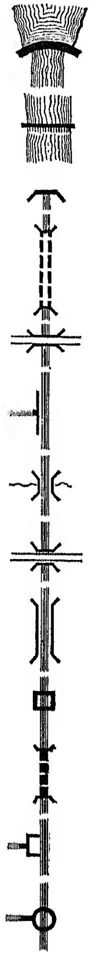
Flume

Check or drop

Siphon or covered conduit

Sluiceway

Turnout



Telephones

Telephone line

Transmission line

TABLE 65

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS, AND AREA AND CIRCUMFERENCE OF CIRCLES OF RADIUS N

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$	πN^2	$2\pi N$
1	1	1	1.0000	1.0000	1.000000	3.142	6.283
2	4	8	1.4142	1.2599	.500000	12.566	12.566
3	9	27	1.7321	1.4422	.333333	28.274	18.850
4	16	64	2.0000	1.5874	.250000	50.265	25.133
5	25	125	2.2361	1.7100	.200000	78.540	31.416
6	36	216	2.4495	1.8171	.166667	113.097	37.699
7	49	343	2.6458	1.9129	.142857	153.938	43.982
8	64	512	2.8284	2.0000	.125000	201.062	50.265
9	81	729	3.0000	2.0801	.111111	254.469	56.549
10	100	1,000	3.1623	2.1544	.100000	314.159	62.832
11	121	1,331	3.3166	2.2240	.090909	380.133	69.115
12	144	1,728	3.4641	2.2894	.083333	452.389	75.398
13	169	2,197	3.6056	2.3513	.076923	530.929	81.681
14	196	2,744	3.7417	2.4101	.071429	615.752	87.965
15	225	3,375	3.8730	2.4662	.066667	706.858	94.248
16	256	4,096	4.0000	2.5198	.062500	804.248	100.531
17	289	4,913	4.1231	2.5713	.058824	907.920	106.814
18	324	5,832	4.2426	2.6207	.055556	1,017.876	113.097
19	361	6,859	4.3589	2.6684	.052632	1,134.115	119.381
20	400	8,000	4.4721	2.7144	.050000	1,256.637	125.664
21	441	9,261	4.5826	2.7589	.047619	1,385.442	131.947
22	484	10,648	4.6904	2.8020	.045455	1,520.531	138.230
23	529	12,167	4.7958	2.8439	.043478	1,661.903	144.513
24	576	13,824	4.8990	2.8845	.041667	1,809.557	150.796
25	625	15,625	5.0000	2.9240	.040000	1,963.495	157.080
26	676	17,576	5.0990	2.9625	.038462	2,123.717	163.363
27	729	19,683	5.1962	3.0000	.037037	2,290.221	169.646
28	784	21,952	5.2915	3.0366	.035714	2,463.009	175.929
29	841	24,389	5.3852	3.0723	.034483	2,642.079	182.212
30	900	27,000	5.4772	3.1072	.033333	2,827.433	188.496
31	961	29,791	5.5678	3.1414	.032258	3,019.071	194.779
32	1,024	32,768	5.6569	3.1748	.031250	3,216.991	201.062
33	1,089	35,937	5.7446	3.2075	.030303	3,421.194	207.345
34	1,156	39,304	5.8310	3.2396	.029412	3,631.681	213.628
35	1,225	42,875	5.9161	3.2711	.028571	3,848.451	219.911
36	1,296	46,656	6.0000	3.3019	.027778	4,071.504	226.195
37	1,369	50,653	6.0828	3.3322	.027027	4,300.840	232.478
38	1,444	54,872	6.1644	3.3620	.026316	4,536.460	238.761
39	1,521	59,319	6.2450	3.3912	.025641	4,778.362	245.044
40	1,600	64,000	6.3246	3.4200	.025000	5,026.548	251.327
41	1,681	68,921	6.4031	3.4482	.024390	5,281.017	257.611
42	1,764	74,088	6.4807	3.4760	.023810	5,541.770	263.894
43	1,849	79,507	6.5574	3.5034	.023256	5,808.805	270.177
44	1,936	85,184	6.6332	3.5303	.022727	6,082.123	276.460
45	2,025	91,125	6.7082	3.5569	.022222	6,361.725	282.743
46	2,116	97,336	6.7823	3.5830	.021739	6,647.610	289.027
47	2,209	103,823	6.8557	3.6088	.021277	6,939.778	295.310
48	2,304	110,592	6.9282	3.6342	.020833	7,238.230	301.593
49	2,401	117,649	7.0000	3.6593	.020408	7,542.964	307.876
50	2,500	125,000	7.0711	3.6840	.020000	7,853.982	314.159

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS, AND AREA AND CIRCUMFERENCE OF CIRCLES OF RADIUS N

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$	πN^2	$2\pi N$
51	2,601	132,651	7.1414	3.7084	.019607	8,171.283	320.442
52	2,704	140,608	7.2111	3.7325	.019231	8,494.867	326.726
53	2,809	148,877	7.2801	3.7563	.018868	8,824.734	333.009
54	2,916	157,464	7.3485	3.7798	.018519	9,160.884	339.292
55	3,025	166,375	7.4162	3.8030	.018182	9,503.318	345.575
56	3,136	175,616	7.4833	3.8259	.017857	9,852.035	351.858
57	3,249	185,193	7.5498	3.8485	.017544	10,207.035	358.142
58	3,364	195,112	7.6158	3.8709	.017241	10,568.318	364.425
59	3,481	205,379	7.6811	3.8930	.016949	10,935.884	370.708
60	3,600	216,000	7.7460	3.9149	.016667	11,309.734	376.991
61	3,721	226,981	7.8102	3.9365	.016393	11,689.866	383.274
62	3,844	238,328	7.8740	3.9579	.016129	12,076.282	389.557
63	3,969	250,047	7.9373	3.9791	.015873	12,468.981	395.841
64	4,096	262,144	8.0000	4.0000	.015625	12,867.964	402.124
65	4,225	274,625	8.0623	4.0207	.015385	13,273.229	408.407
66	4,356	287,496	8.1240	4.0412	.015156	13,684.778	414.690
67	4,489	300,763	8.1854	4.0615	.014925	14,102.610	420.973
68	4,624	314,432	8,2462	4.0817	.014706	14,526.725	427.257
69	4,761	328,509	8.3066	4.1016	.014493	14,957.123	433.540
70	4,900	343,000	8.3666	4.1213	.014286	15,393.804	439.823
71	5,041	357,911	8.4261	4.1408	.014085	15,836.769	446.106
72	5,184	373,248	8.4853	4.1602	.013889	16,286.017	452.389
73	5,329	389,017	8.5440	4.1793	.013699	16,741.547	458.673
74	5,476	405,224	8.6023	4.1983	.013514	17,203.362	464.956
75	5,625	421,875	8.6603	4.2172	.013333	17,671.459	471.239
76	5,776	438,976	8.7178	4.2358	.013158	18,145.839	477.522
77	5,929	456,533	8.7750	4.2543	.012987	18,626.503	483.805
78	6,084	474,552	8.8318	4.2727	.012821	19,113.450	490.088
79	6,241	493,039	8.8882	4.2908	.012658	19,606.680	486.372
80	6,400	512,000	8.9443	4.3089	.012500	20,106.193	502.655
81	6,561	531,441	9.0000	4.3267	.012346	20,611.990	508.938
82	6,724	551,368	9.0554	4.3445	.012195	21,124.069	515.221
83	6,889	571,787	9.1104	4.3621	.012048	21,642.432	521.504
84	7,056	592,704	9.1652	4.3795	.011905	22,167.078	527.788
85	7,225	614,125	9.2195	4.3968	.011765	22,698.007	534.071
86	7,396	636,056	9.2736	4.4140	.011628	23,235.220	540.354
87	7,569	658,503	9.3274	4.4310	.011494	23,778.715	546.637
88	7,744	681,472	9.3808	4.4480	.011364	24,328.494	552.920
89	7,921	704,969	9.4340	4.4647	.011236	24,884.556	559.205
90	8,100	729,000	9.4868	4.4814	.011111	25,446.901	565.487
91	8,281	753,571	9.5394	4.4979	.010989	26,015.529	571.770
92	8,464	778,688	9.5917	4.5144	.010870	26,590.441	578.053
93	8,649	804,357	9.6437	4.5307	.010753	27,171.635	584.336
94	8,836	830,584	9.6954	4.5468	.010638	27,759.113	590.619
95	9,025	857,375	9.7468	4.5629	.010526	28,352.874	596.903
96	9,216	884,736	9.7980	4.5789	.010417	28,952.918	603.186
97	9,409	912,673	9.8489	4.5947	.010309	29,559.246	609.469
98	9,604	941,192	9.8995	4.6104	.010204	30,171.856	615.752
99	9,801	970,299	9.9499	4.6261	.010101	30,790.750	622.035
100	10,000	1,000,000	10.0000	4.6416	.010000	31,415.927	628.319

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
101	10,201	1,030,301	10.0498756	4.6570095	.009900990
102	10,404	1,061,208	10.0995049	4.6723287	.009803922
103	10,609	1,092,727	10.1488916	4.6875482	.009708738
104	10,816	1,124,864	10.1980390	4.7026694	.009615385
105	11,025	1,157,625	10.2469508	4.7176940	.009523810
106	11,236	1,191,016	10.2956301	4.7326235	.009433962
107	11,449	1,225,043	10.3440804	4.7474594	.009345794
108	11,664	1,259,712	10.3923048	4.7622032	.009259259
109	11,881	1,295,029	10.4403065	4.7768562	.009174312
110	12,100	1,331,000	10.4880885	4.7914199	.009090909
111	12,321	1,367,631	10.5356538	4.8058955	.009009009
112	12,544	1,404,928	10.5830052	4.8202845	.008928571
113	12,769	1,442,897	10.6301458	4.8345881	.008849558
114	12,996	1,481,544	10.6770783	4.8488076	.008771930
115	13,225	1,520,875	10.7238053	4.8629442	.008695652
116	13,456	1,560,896	10.7703296	4.8769990	.008620690
117	13,689	1,601,613	10.8166538	4.8909732	.008547009
118	13,924	1,643,032	10.8627805	4.9048681	.008474576
119	14,161	1,685,159	10.9087121	4.9186847	.008403361
120	14,400	1,728,000	10.9544512	4.9324242	.008333333
121	14,641	1,771,561	11.0000000	4.9460874	.008264463
122	14,884	1,815,848	11.0453610	4.9596757	.008196721
123	15,129	1,860,867	11.0905365	4.9731898	.008130081
124	15,376	1,906,624	11.1355287	4.9866310	.008064516
125	15,625	1,953,125	11.1803399	5.0000000	.008000000
126	15,876	2,000,376	11.2249722	5.0132979	.007936508
127	16,129	2,048,383	11.2694277	5.0265257	.007874016
128	16,384	2,097,152	11.3137085	5.0396842	.007812500
129	16,641	2,146,689	11.3578167	5.0527743	.007751938
130	16,900	2,197,000	11.4017543	5.0657970	.007692308
131	17,161	2,248,091	11.4455231	5.0787531	.007633588
132	17,424	2,299,968	11.4891253	5.0916434	.007575758
133	17,689	2,352,637	11.5325626	5.1044687	.007518797
134	17,956	2,406,104	11.5758369	5.1172299	.007462687
135	18,225	2,460,375	11.6189500	5.1299278	.007407407
136	18,496	2,515,456	11.6619038	5.1425632	.007352941
137	18,769	2,571,353	11.7046999	5.1551367	.007299270
138	19,044	2,628,072	11.7473401	5.1676493	.007246377
139	19,321	2,685,619	11.7898261	5.1801015	.007194245
140	19,600	2,744,000	11.8321596	5.1924941	.007142857
141	19,881	2,803,221	11.8743421	5.2048279	.007092199
142	20,164	2,863,288	11.9163753	5.2171034	.007042254
143	20,449	2,924,207	11.9582607	5.2293215	.006993007
144	20,736	2,985,984	12.0000000	5.2414828	.006944444
145	21,025	3,048,625	12.0415946	5.2535879	.006896552
146	21,316	3,112,136	12.0830460	5.2656374	.006849315
147	21,609	3,176,523	12.1243557	5.2776321	.006802721
148	21,904	3,241,792	12.1655251	5.2895725	.006756757
149	22,201	3,307,949	12.2065556	5.3014592	.006711409
150	22,500	3,375,000	12.2474487	5.3132928	.006666667

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
151	22,801	3,442,951	12.2882057	5.3250740	.006622517
152	23,104	3,511,808	12.3288280	5.3368033	.006578947
153	23,409	3,581,577	12.3693769	5.3484812	.006535948
154	23,716	3,652,264	12.4096736	5.3601084	.006493506
155	24,025	3,723,875	12.4498996	5.3716854	.006451613
156	24,336	3,796,416	12.4899960	5.3832126	.006410256
157	24,649	3,869,893	12.5299641	5.3946907	.006369427
158	24,964	3,944,312	12.5698051	5.4061202	.006329114
159	25,281	4,019,679	12.6095202	5.4175015	.006289308
160	25,600	4,096,000	12.6491106	5.4288352	.006250000
161	25,921	4,173,281	12.6885775	5.4401218	.006211180
162	26,244	4,251,528	12.7279221	5.4513618	.006172840
163	26,569	4,330,747	12.7671453	5.4625556	.006134969
164	26,896	4,410,944	12.8062485	5.4737037	.006097561
165	27,225	4,492,125	12.8452326	5.4848066	.006060606
166	27,556	4,574,296	12.8840987	5.4958647	.006024096
167	27,889	4,657,463	12.9228480	5.5068784	.005988024
168	28,224	4,741,632	12.9614814	5.5178484	.005952381
169	28,561	4,826,809	13.0000000	5.5287748	.005917160
170	28,900	4,913,000	13.0384048	5.5396583	.005882353
171	29,241	5,000,211	13.0766968	5.5504991	.005847953
172	29,584	5,088,448	13.1148770	5.5612978	.005813953
173	29,929	5,177,717	13.1529464	5.5720546	.005780347
174	30,276	5,268,024	13.1909060	5.5827702	.005747126
175	30,625	5,359,375	13.2287566	5.5934447	.005714286
176	30,976	5,451,776	13.2664992	5.6040787	.005681818
177	31,329	5,545,233	13.3041347	5.6146724	.005649718
178	31,684	5,639,752	13.3416641	5.6252263	.005617978
179	32,041	5,735,339	13.3790882	5.6357408	.005586592
180	32,400	5,832,000	13.4164079	5.6462162	.005555556
181	32,761	5,929,741	13.4536240	5.6566528	.005524862
182	33,124	6,028,568	13.4907376	5.6670511	.005494505
183	33,489	6,128,487	13.5277493	5.6774114	.005464481
184	33,856	6,229,504	13.5646600	5.6877340	.005434783
185	34,225	6,331,625	13.6014705	5.6980192	.005405405
186	34,596	6,434,856	13.6381817	5.7082675	.005376344
187	34,969	6,539,203	13.6747943	5.7184791	.005347594
188	35,344	6,644,672	13.7113092	5.7286543	.005319149
189	35,721	6,751,269	13.7477271	5.7387936	.005291005
190	36,100	6,859,000	13.7840488	5.7488971	.005263158
191	36,481	6,967,871	13.8202750	5.7589652	.005235602
192	36,864	7,077,888	13.8564065	5.7689982	.005208333
193	37,249	7,189,057	13.8924440	5.7789966	.005181347
194	37,636	7,301,384	13.9283883	5.7889604	.005154639
195	38,025	7,414,875	13.9642400	5.7988900	.005128205
196	38,416	7,529,536	14.0000000	5.8087857	.005102041
197	38,809	7,645,373	14.0356688	5.8186479	.005076142
198	39,204	7,762,392	14.0712473	5.8284767	.005050505
199	39,610	7,880,599	14.1067360	5.8382725	.005025126
200	40,000	8,000,000	14.1421356	5.8480355	.005000000

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
201	40,401	8,120,601	14.1774469	5.8577660	.004975124
202	40,804	8,242,408	14.2126704	5.8674643	.004950495
203	41,209	8,365,427	14.2478068	5.8771307	.004926108
204	41,616	8,489,664	14.2828569	5.8867653	.004901961
205	42,025	8,615,125	14.3178211	5.8963685	.004878049
206	42,436	8,741,816	14.3527001	5.9059406	.004854369
207	42,849	8,869,743	14.3874946	5.9154817	.004830918
208	43,264	8,998,912	14.4222051	5.9249921	.004807692
209	43,681	9,129,329	14.4568323	5.9344721	.004784689
210	44,100	9,261,000	14.4913767	5.9439220	.004761905
211	44,521	9,393,931	14.5258390	5.9533418	.004739336
212	44,944	9,528,128	14.5602198	5.9627320	.004716981
213	45,369	9,663,597	14.5945195	5.9720926	.004694836
214	45,796	9,800,344	14.6287388	5.9814240	.004672897
215	46,225	9,938,375	14.6628783	5.9907264	.004651163
216	46,656	10,077,696	14.6969385	6.0000000	.004629630
217	47,089	10,218,313	14.7309199	6.0092450	.004608295
218	47,524	10,360,232	14.7648231	6.0184617	.004587156
219	47,961	10,503,459	14.7986486	6.0276502	.004566210
220	48,400	10,648,000	14.8323970	6.0368107	.004545455
221	48,841	10,793,861	14.8660687	6.0459435	.004524887
222	49,284	10,941,048	14.8996644	6.0550489	.004504505
223	49,729	11,089,567	14.9331845	6.0641270	.004484305
224	50,176	11,239,424	14.9666295	6.0731779	.004464286
225	50,625	11,390,625	15.0000000	6.0822020	.004444444
226	51,076	11,543,176	15.0332964	6.0911994	.004434779
227	51,529	11,697,083	15.0665192	6.1001702	.004405286
228	51,984	11,852,352	15.0996689	6.1091147	.004385965
229	52,441	12,008,989	15.1327460	6.1180332	.004366812
230	52,900	12,167,000	15.1657509	6.1269257	.004347826
231	53,361	12,326,391	15.1986842	6.1357924	.004329004
232	53,824	12,487,168	15.2315462	6.1446337	.004310345
233	54,289	12,649,337	15.2643375	6.1534495	.004291845
234	54,756	12,812,904	15.2970585	6.1622401	.004273504
235	55,225	12,977,875	15.3297097	6.1710058	.004255319
236	55,696	13,144,256	15.3622915	6.1797466	.004237288
237	56,169	13,312,053	15.3948043	6.1884628	.004219409
238	56,644	13,481,272	15.4272486	6.1971544	.004201681
239	57,121	13,651,919	15.4596248	6.2058218	.004184100
240	57,600	13,824,000	15.4919334	6.2144650	.004166667
241	58,081	13,997,521	15.5241747	6.2230843	.004149378
242	58,564	14,172,488	15.5563492	6.2316797	.004132231
243	59,049	14,348,907	15.5884573	6.2402515	.004115226
244	59,536	14,526,784	15.6204994	6.2487998	.004098361
245	60,025	14,706,125	15.6524758	6.2573248	.004081633
246	60,516	14,886,936	15.6843871	6.2658266	.004065041
247	61,009	15,069,223	15.7162336	6.2743054	.004048583
248	61,504	15,252,992	15.7480157	6.2827613	.004032258
249	62,001	15,438,249	15.7797338	6.2911946	.004016064
250	62,500	15,625,000	15.8113883	6.2996053	.004000000

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
251	63,001	15,813,251	15.8429795	6.3079935	.003984064
252	63,504	16,003,008	15.8745079	6.3163596	.003968254
253	64,009	16,194,277	15.9059737	6.3247035	.003952569
254	64,516	16,387,064	15.9373775	6.3330256	.003937008
255	65,025	16,581,375	15.9687194	6.3413257	.003921569
256	65,536	16,777,216	16.0000000	6.3496042	.003906250
257	66,049	16,974,593	16.0312195	6.3578611	.003891051
258	66,564	17,173,512	16.0623784	6.3660968	.003875969
259	67,081	17,373,979	16.0934769	6.3743111	.003861004
260	67,600	17,576,000	16.1245155	6.3825043	.003846154
261	68,121	17,779,581	16.1554944	6.3906765	.003831418
262	68,644	17,984,728	16.1864141	6.3988279	.003816794
263	69,169	18,191,447	16.2172747	6.4069585	.003802281
264	69,696	18,399,744	16.2480768	6.4150687	.003787879
265	70,225	18,609,625	16.2788206	6.4231583	.003773585
266	70,756	18,821,096	16.3095064	6.4312276	.003759398
267	71,289	19,034,163	16.3401346	6.4392767	.003745318
268	71,824	19,248,832	16.3707055	6.4473057	.003731343
269	72,361	19,465,109	16.4012195	6.4553148	.003717472
270	72,900	19,683,000	16.4316767	6.4633041	.003703704
271	73,441	19,902,511	16.4620776	6.4712736	.003690037
272	73,984	20,123,648	16.4924225	6.4792236	.003676471
273	74,529	20,346,417	16.5227116	6.4871541	.003663004
274	75,076	20,570,824	16.5529454	6.4950653	.003649635
275	75,625	20,796,875	16.5831240	6.5029572	.003636364
276	76,176	21,024,576	16.6132477	6.5108300	.003623188
277	76,729	21,253,933	16.6433170	6.5186839	.003610108
278	77,284	21,484,952	16.6733320	6.5265189	.003597122
279	77,841	21,717,639	16.7032931	6.5343351	.003584229
280	78,400	21,952,000	16.7332005	6.5421326	.003571429
281	78,961	22,188,041	16.7630546	6.5499116	.003558719
282	79,524	22,425,768	16.7928556	6.5576722	.003546099
283	80,089	22,665,187	16.8226038	6.5654144	.003533569
284	80,656	22,906,304	16.8522995	6.5731385	.003521127
285	81,225	23,149,125	16.8819430	6.5808443	.003508772
286	81,796	23,393,656	16.9115345	6.5885323	.003496503
287	82,369	23,639,903	16.9410743	6.5962023	.003484321
288	82,944	23,887,872	16.9705627	6.6038545	.003472222
289	83,521	24,137,569	17.0000000	6.6114890	.003460208
290	84,100	24,389,000	17.0293864	6.6191060	.003448276
291	84,681	24,642,171	17.0587221	6.6267054	.003436426
292	85,264	24,897,088	17.0880075	6.6342874	.003424658
293	85,849	25,153,757	17.1172428	6.6418522	.003412969
294	86,436	25,412,184	17.1464282	6.6493998	.003401361
295	87,025	25,672,375	17.1755640	6.6569302	.003389831
296	87,616	25,934,336	17.2046505	6.6644437	.003378378
297	88,209	26,198,073	17.2336879	6.6719403	.003367003
298	88,804	26,463,592	17.2626765	6.6794200	.003355705
299	89,401	26,730,899	17.2916165	6.6868831	.003344482
300	90,000	27,000,000	17.3205081	6.6943295	.003333333

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
301	90,601	27,270,901	17.3493516	6.7017593	.003322259
302	91,204	27,543,608	17.3781472	6.7091729	.003311258
303	91,809	27,818,127	17.4068952	6.7165700	.003300330
304	92,416	28,094,464	17.4355958	6.7239508	.003289474
305	93,025	28,372,625	17.4642492	6.7313155	.003278689
306	93,636	28,652,616	17.4928557	6.7386641	.003267974
307	94,249	28,934,443	17.5214155	6.7459967	.003257329
308	94,864	29,218,112	17.5499288	6.7533134	.003246753
309	95,481	29,503,629	17.5783958	6.7606143	.003236246
310	96,100	29,791,000	17.6068169	6.7678995	.003225806
311	96,721	30,080,231	17.6351921	6.7751690	.003215434
312	97,344	30,371,328	17.6635217	6.7824229	.003205128
313	97,969	30,664,297	17.6918060	6.7896613	.003194888
314	98,596	30,959,144	17.7200451	6.7968844	.003184713
315	99,225	31,255,875	17.7482393	6.8040921	.003174603
316	99,856	31,554,496	17.7763888	6.8112847	.003164557
317	100,489	31,855,013	17.8044938	6.8184620	.003154574
318	101,124	32,157,432	17.8325545	6.8256242	.003144654
319	101,761	32,461,759	17.8605711	6.8327714	.003134796
320	102,400	32,768,000	17.8885438	6.8399037	.003125000
321	103,041	33,076,161	17.9164729	6.8470213	.003115265
322	103,684	33,386,248	17.9443584	6.8541240	.003105590
323	104,329	33,698,267	17.9722008	6.8612120	.003095975
324	104,976	34,012,224	18.0000000	6.8682855	.003086420
325	105,625	34,328,125	18.0277564	6.8753443	.003076923
326	106,276	34,645,976	18.0554701	6.8823888	.003067485
327	106,929	34,965,783	18.0831413	6.8894188	.003058104
328	107,584	35,287,552	18.1107703	6.8964345	.003048780
329	108,241	35,611,289	18.1383571	6.9034359	.003039514
330	108,900	35,937,000	18.1659021	6.9104232	.003030303
331	109,561	36,264,691	18.1934054	6.9173964	.003021148
332	110,224	36,594,368	18.2208672	6.9243556	.003012048
333	110,889	36,926,037	18.2482876	6.9313008	.003003003
334	111,556	37,259,704	18.2756669	6.9382321	.002994012
335	112,225	37,595,375	18.3030052	6.9451496	.002985075
336	112,896	37,933,056	18.3303028	6.9520533	.002976190
337	113,569	38,272,753	18.3575598	6.9589434	.002967359
338	114,244	38,614,472	18.3847763	6.9658198	.002958580
339	114,921	38,958,219	18.4119526	6.9726826	.002949853
340	115,600	39,304,000	18.4390889	6.9795321	.002941176
341	116,281	39,651,821	18.4661853	6.9863681	.002932551
342	116,964	40,001,688	18.4932420	6.9931906	.002923977
343	117,649	40,353,607	18.5202592	7.0000000	.002915452
344	118,336	40,707,584	18.5472370	7.0067962	.002906977
345	119,025	41,063,625	18.5741756	7.0135791	.002898551
346	119,716	41,421,736	18.6010752	7.0203490	.002890173
347	120,409	41,781,923	18.6279360	7.0271058	.002881844
348	121,104	42,144,192	18.6547581	7.0338497	.002873563
349	121,801	42,508,549	18.6815417	7.0405806	.002865330
350	122,500	42,875,000	18.7082869	7.0472987	.002857143

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
351	123,201	43,243,551	18.7349940	7.0540041	.002849003
352	123,904	43,614,208	18.7616630	7.0606967	.002840909
353	124,609	43,986,977	18.7882942	7.0673767	.002832861
354	125,316	44,361,864	18.8148877	7.0740440	.002824859
355	126,025	44,738,875	18.8414437	7.0806988	.002816901
356	126,736	45,118,016	18.8679623	7.0873411	.002808989
357	127,449	45,499,293	18.8944436	7.0939709	.002801120
358	128,164	45,882,712	18.9208879	7.1005885	.002793296
359	128,881	46,268,279	18.9472953	7.1071937	.002785515
360	129,600	46,656,000	18.9736660	7.1137866	.002777778
361	130,321	47,045,881	19.0000000	7.1203674	.002770083
362	131,044	47,437,928	19.0262976	7.1269360	.002762431
363	131,769	47,832,147	19.0525589	7.1334925	.002754821
364	132,496	48,228,544	19.0787840	7.1400370	.002747253
365	133,225	48,627,125	19.1049732	7.1465695	.002739726
366	133,956	49,027,896	19.1311265	7.1530901	.002732240
367	134,689	49,430,863	19.1572441	7.1595988	.002724796
368	135,424	49,836,032	19.1833261	7.1660957	.002717391
369	136,161	50,243,409	19.2093727	7.1725809	.002710027
370	136,900	50,653,000	19.2353841	7.1790544	.002702703
371	137,641	51,064,811	19.2613603	7.1855162	.002695418
372	138,384	51,478,848	19.2873015	7.1919663	.002688172
373	139,129	51,895,117	19.3132079	7.1984050	.002680965
374	139,876	52,313,624	19.3390796	7.2048322	.002673797
375	140,625	52,734,375	19.3649167	7.2112479	.002666667
376	141,376	53,157,376	19.3907194	7.2176522	.002659574
377	142,129	53,582,633	19.4164878	7.2240450	.002652520
378	142,884	54,010,152	19.4422221	7.2304268	.002645503
379	143,641	54,439,939	19.4679223	7.2367972	.002638522
380	144,400	54,872,000	19.4935887	7.2431565	.002631579
381	145,161	55,306,341	19.5192213	7.2495045	.002624672
382	145,924	55,742,968	19.5448203	7.2558415	.002617801
383	146,689	56,181,887	19.5703858	7.2621675	.002610966
384	147,456	56,623,104	19.5959179	7.2684824	.002604167
385	148,225	57,066,625	19.6214169	7.2747864	.002597403
386	148,996	57,512,456	19.6468827	7.2810794	.002590674
387	149,769	57,960,603	19.6723156	7.2873617	.002583979
388	150,544	58,411,072	19.6977156	7.2936330	.002577320
389	151,321	58,863,869	19.7230829	7.2998936	.002570694
390	152,100	59,319,000	19.7484177	7.3061436	.002564103
391	152,881	59,776,471	19.7737199	7.3123828	.002557545
392	153,664	60,236,288	19.7989899	7.3186114	.002551020
393	154,449	60,698,457	19.8242276	7.3248295	.002544529
394	155,236	61,162,984	19.8494332	7.3310369	.002538071
395	156,025	61,629,875	19.8746069	7.3372339	.002531646
396	156,816	62,099,136	19.8997487	7.3434205	.002525253
397	157,609	62,570,773	19.9248588	7.3495966	.002518892
398	158,404	63,044,792	19.9499373	7.3557624	.002512563
399	159,201	63,521,199	19.9749844	7.3619178	.002506266
400	160,000	64,000,000	20.0000000	7.3680630	.002500000

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
401	160,801	64,481,201	20.0249844	7.3741979	.002493766
402	161,604	64,964,808	20.0499377	7.3803227	.002487562
403	162,409	65,450,827	20.0748599	7.3864373	.002481390
404	163,216	65,939,264	20.0997512	7.3925418	.002475248
405	164,025	66,430,125	20.1246118	7.3986363	.002469136
406	164,836	66,923,416	20.1494417	7.4047206	.002463054
407	165,649	67,419,143	20.1742410	7.4107950	.002457002
408	166,464	67,917,312	20.1990099	7.4168595	.002450980
409	167,281	68,417,929	20.2237484	7.4229142	.002444988
410	168,100	68,921,000	20.2484567	7.4289589	.002439024
411	168,921	69,426,531	20.2731349	7.4349938	.002433090
412	169,744	69,934,528	20.2977831	7.4410189	.002427184
413	170,569	70,444,997	20.3224014	7.4470342	.002421308
414	171,396	70,957,944	20.3469899	7.4530399	.002415459
415	172,225	71,473,375	20.3715488	7.4590359	.002409639
416	173,056	71,991,296	20.3960781	7.4650223	.002403846
417	173,889	72,511,713	20.4205779	7.4709991	.002398082
418	174,724	73,034,632	20.4450483	7.4769664	.002392344
419	175,561	73,560,059	20.4694895	7.4829242	.002386635
420	176,400	74,088,000	20.4939015	7.4888724	.002380952
421	177,241	74,618,461	20.5182845	7.4948113	.002375297
422	178,084	75,151,448	20.5426386	7.5007406	.002369668
423	178,929	75,686,967	20.5669638	7.5066607	.002364066
424	179,776	76,225,024	20.5912603	7.5125715	.002358491
425	180,625	76,765,625	20.6155281	7.5184730	.002352941
426	181,476	77,308,776	20.6397674	7.5243652	.002347418
427	182,329	77,854,483	20.6639783	7.5302482	.002341920
428	183,184	78,402,752	20.6881609	7.5361221	.002336449
429	184,041	78,953,589	20.7123152	7.5419867	.002331002
430	184,900	79,507,000	20.7364414	7.5478423	.002325581
431	185,761	80,062,991	20.7605395	7.5536888	.002320186
432	186,624	80,621,568	20.7846097	7.5595263	.002314815
433	187,489	81,182,737	20.8086520	7.5653548	.002309469
434	188,356	81,746,504	20.8326667	7.5711743	.002304147
435	189,225	82,312,875	20.8566536	7.5769849	.002298851
436	190,096	82,881,856	20.8806130	7.5827865	.002293578
437	190,969	83,453,453	20.9045450	7.5885793	.002288330
438	191,844	84,027,672	20.9284495	7.5943633	.002283105
439	192,721	84,604,519	20.9523268	7.6001385	.002277904
440	193,600	85,184,000	20.9761770	7.6059049	.002272727
441	194,481	85,766,121	21.0000000	7.6116626	.002267574
442	195,364	86,350,888	21.0237960	7.6174116	.002262443
443	196,249	86,938,307	21.0475652	7.6231519	.002257336
444	197,136	87,528,384	21.0713075	7.6288837	.002252252
445	198,025	88,121,125	21.0950231	7.6346067	.002247191
446	198,916	88,716,536	21.1187121	7.6403213	.002242152
447	199,809	89,314,623	21.1423745	7.6460272	.002237136
448	200,704	89,915,392	21.1660105	7.6517247	.002232143
449	201,601	90,518,849	21.1896201	7.6574138	.002227171
450	202,500	91,125,000	21.2132034	7.6630943	.002222222

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
451	203,401	91,733,851	21.2367606	7.6687665	.002217295
452	204,304	92,345,408	21.2602916	7.6744303	.002212389
453	205,209	92,959,677	21.2837967	7.6800857	.002207506
454	206,116	93,576,664	21.3072758	7.6857328	.002202643
455	207,025	94,196,375	21.3307290	7.6913717	.002197802
456	207,936	94,818,816	21.3541565	7.6970023	.002192982
457	208,849	95,443,993	21.3775583	7.7026246	.002188184
458	209,764	96,071,912	21.4009346	7.7082388	.002183406
459	210,681	96,702,579	21.4242853	7.7138448	.002178649
460	211,600	97,336,000	21.4476106	7.7194426	.002173913
461	212,521	97,972,181	21.4709106	7.7250325	.002169197
462	213,444	98,611,128	21.4941853	7.7306141	.002164502
463	214,369	99,252,847	21.5174348	7.7361877	.002159827
464	215,296	99,897,344	21.5406592	7.7417532	.002155172
465	216,225	100,544,625	21.5638587	7.7473109	.002150538
466	217,156	101,194,696	21.5870331	7.7528606	.002145923
467	218,089	101,847,563	21.6101828	7.7584023	.002141328
468	219,024	102,503,232	21.6333077	7.7639361	.002136752
469	219,961	103,161,709	21.6564078	7.7694620	.002132196
470	220,900	103,823,000	21.6794834	7.7749801	.002127660
471	221,841	104,487,111	21.7025344	7.7804904	.002123142
472	222,784	105,154,048	21.7255610	7.7859928	.002118644
473	223,729	105,823,817	21.7485632	7.7914875	.002114165
474	224,676	106,496,424	21.7715411	7.7969745	.002109705
475	225,625	107,171,875	21.7944947	7.8024538	.002105263
476	226,576	107,850,176	21.8174242	7.8079254	.002100840
477	227,529	108,531,333	21.8403297	7.8133892	.002096436
478	228,484	109,215,352	21.8632111	7.8188456	.002092050
479	229,441	109,902,239	21.8860686	7.8242942	.002087683
480	230,400	110,592,000	21.9089023	7.8297353	.002083333
481	231,361	111,284,641	21.9317122	7.8351688	.002079002
482	232,324	111,980,168	21.9544984	7.8405949	.002074689
483	233,289	112,678,587	21.9772610	7.8460134	.002070393
484	234,256	113,379,904	22.0000000	7.8514244	.002066116
485	235,225	114,084,125	22.0227155	7.8568281	.002061856
486	236,196	114,791,256	22.0454077	7.8622242	.002057613
487	237,169	115,501,303	22.0680765	7.8676130	.002053388
488	238,144	116,214,272	22.0907220	7.8729944	.002049180
489	239,121	116,930,169	22.1133444	7.8783684	.002044990
490	240,100	117,649,000	22.1359436	7.8837352	.002040816
491	241,081	118,370,771	22.1585198	7.8890946	.002036660
492	242,064	119,095,488	22.1810730	7.8944468	.002032520
493	243,049	119,823,157	22.2036033	7.8997917	.002028398
494	244,036	120,553,784	22.2261108	7.9051294	.002024291
495	245,025	121,287,375	22.2485955	7.9104599	.002020202
496	246,016	122,023,936	22.2710575	7.9157832	.002016129
497	247,009	122,763,473	22.2934968	7.9210994	.002012072
498	248,004	123,505,992	22.3159136	7.9264085	.002008032
499	249,001	124,251,499	22.3383079	7.9317104	.002004008
500	250,000	125,000,000	22.3606798	7.9370053	.002000000

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
501	251,001	125,751,501	22.3830293	7.9422931	.001996008
502	252,004	126,506,008	22.4053565	7.9475739	.001992032
503	253,009	127,263,527	22.4276615	7.9528477	.001988072
504	254,016	128,024,064	22.4499443	7.9581144	.001984127
505	255,025	128,787,625	22.4722051	7.9633743	.001980198
506	256,036	129,554,216	22.4944438	7.9686271	.001976285
507	257,049	130,323,843	22.5166605	7.9738731	.001972387
508	258,064	131,096,512	22.5388553	7.9791122	.001968504
509	259,081	131,872,229	22.5610283	7.9843444	.001964637
510	260,100	132,651,000	22.5831796	7.9895697	.001960784
511	261,121	133,432,831	22.6053091	7.9947883	.001956947
512	262,144	134,217,728	22.6274170	8.0000000	.001953125
513	263,169	135,005,697	22.6495033	8.0052049	.001949318
514	264,196	135,796,744	22.6715681	8.0104032	.001945525
515	265,225	136,590,875	22.6936114	8.0155946	.001941748
516	266,256	137,388,096	22.7156334	8.0207794	.001937984
517	267,289	138,188,413	22.7376340	8.0259574	.001934236
518	268,324	138,991,832	22.7596134	8.0311287	.001930502
519	269,361	139,798,359	22.7815715	8.0362935	.001926782
520	270,400	140,608,000	22.8035085	8.0414515	.001923077
521	271,441	141,420,761	22.8254244	8.0466030	.001919386
522	272,484	142,236,648	22.8473193	8.0517479	.001915709
523	273,529	143,055,667	22.8691933	8.0568862	.001912046
524	274,576	143,877,824	22.8910463	8.0620180	.001908397
525	275,625	144,703,125	22.9128785	8.0671432	.001904762
526	276,676	145,531,576	22.9346899	8.0722620	.001901141
527	277,729	146,363,183	22.9564806	8.0773743	.001897533
528	278,784	147,197,952	22.9782506	8.0824800	.001893939
529	279,841	148,035,889	23.0000000	8.0875794	.001890359
530	280,900	148,877,000	23.0217289	8.0926723	.001886792
531	281,961	149,721,291	23.0434372	8.0977589	.001883239
532	283,024	150,568,768	23.0651252	8.1028390	.001879699
533	284,089	151,419,437	23.0867928	8.1079128	.001876173
534	285,156	152,273,304	23.1084400	8.1129803	.001872659
535	286,225	153,130,375	23.1300670	8.1180414	.001869159
536	287,296	153,990,656	23.1516738	8.1230962	.001865672
537	288,369	154,854,153	23.1732605	8.1281447	.001862197
538	289,444	155,720,872	23.1948270	8.1331870	.001858736
539	290,521	156,590,819	23.2163735	8.1382230	.001855288
540	291,600	157,464,000	23.2379001	8.1432529	.001851852
541	292,681	158,340,421	23.2594067	8.1482765	.001848429
542	293,764	159,220,088	23.2808935	8.1532939	.001845018
543	294,849	160,103,007	23.3023604	8.1583051	.001841621
544	295,936	160,989,184	23.3238076	8.1633102	.001838235
545	297,025	161,878,625	23.3452351	8.1683092	.001834862
546	298,116	162,771,336	23.3666429	8.1733020	.001831502
547	299,209	163,667,323	23.3880311	8.1782888	.001828154
548	300,304	164,566,592	23.4093998	8.1832695	.001824818
549	301,401	165,469,149	23.4307490	8.1882441	.001821494
550	302,500	166,375,000	23.4520788	8.1932127	.001818182

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
551	303,601	167,284,151	23.4733892	8.1981753	.001814882
552	304,704	168,196,608	23.4946802	8.2031319	.001811594
553	305,809	169,112,377	23.5159520	8.2080825	.001808318
554	306,916	170,031,464	23.5372046	8.2130271	.001805054
555	308,025	170,953,875	23.5584380	8.2179657	.001801802
556	309,136	171,879,616	23.5796522	8.2228985	.001798561
557	310,249	172,808,693	23.6008474	8.2278254	.001795332
558	311,364	173,741,112	23.6220236	8.2327463	.001792115
559	312,481	174,676,879	23.6431808	8.2376614	.001788909
560	313,600	175,616,000	23.6643191	8.2425706	.001785714
561	314,721	176,558,481	23.6854386	8.2474740	.001782531
562	315,844	177,504,328	23.7065392	8.2523715	.001779359
563	316,969	178,453,547	23.7276210	8.2572633	.001776199
564	318,096	179,406,144	23.7486842	8.2621492	.001773050
565	319,225	180,362,125	23.7697286	8.2670294	.001769912
566	320,356	181,321,496	23.7907545	8.2719039	.001766784
567	321,489	182,284,263	23.8117618	8.2767726	.001763668
568	322,624	183,250,432	23.8327506	8.2816355	.001760563
569	323,761	184,220,009	23.8537209	8.2864928	.001757469
570	324,900	185,193,000	23.8746728	8.2913444	.001754386
571	326,041	186,169,411	23.8956063	8.2961903	.001751313
572	327,184	187,149,248	23.9165215	8.3010304	.001748252
573	328,329	188,132,517	23.9374184	8.3058651	.001745201
574	329,476	189,119,224	23.9582971	8.3106941	.001742160
575	330,625	190,109,375	23.9791576	8.3155175	.001739130
576	331,776	191,102,976	24.0000000	8.3203353	.001736111
577	332,929	192,100,033	24.0208243	8.3251475	.001733102
578	334,084	193,100,552	24.0416306	8.3299542	.001730104
579	335,241	194,104,539	24.0624188	8.3347553	.001727116
580	336,400	195,112,000	24.0831891	8.3395509	.001724138
581	337,561	196,122,941	24.1039416	8.3443410	.001721170
582	338,724	197,137,368	24.1246762	8.3491256	.001718213
583	339,889	198,155,287	24.1453929	8.3539047	.001715266
584	341,056	199,176,704	24.1660919	8.3586784	.001712329
585	342,225	200,201,625	24.1867732	8.3634466	.001709402
586	343,396	201,230,056	24.2074369	8.3682095	.001706485
587	344,569	202,262,003	24.2280829	8.3729668	.001703578
588	345,744	203,297,472	24.2487113	8.3777188	.001700680
589	346,921	204,336,469	24.2693222	8.3824653	.001697793
590	348,100	205,379,000	24.2899156	8.3872065	.001694915
591	349,281	206,425,071	24.3104916	8.3919423	.001692047
592	350,464	207,474,688	24.3310501	8.3966729	.001689189
593	351,649	208,527,857	24.3515913	8.4013981	.001686341
594	352,836	209,584,584	24.3721152	8.4061180	.001683502
595	354,025	210,644,875	24.3926218	8.4108326	.001680672
596	355,216	211,708,736	24.4131112	8.4155419	.001677852
597	356,409	212,776,173	24.4335834	8.4202460	.001675042
598	357,604	213,847,192	24.4540385	8.4249448	.001672241
599	358,801	214,921,799	24.4744765	8.4296383	.001669449
600	360,000	216,000,000	24.4948974	8.4343267	.001666667

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
601	361,201	217,081,801	24.5153013	8.4390098	.001663894
602	362,404	218,167,208	24.5356883	8.4436877	.001661130
603	363,609	219,256,227	24.5560583	8.4483605	.001658375
604	364,816	220,348,864	24.5764115	8.4530281	.001655629
605	366,025	221,445,125	24.5967478	8.4576906	.001652893
606	367,236	222,545,016	24.6170673	8.4623479	.001650165
607	368,449	223,648,543	24.6373700	8.4670001	.001647446
608	369,664	224,755,712	24.6576560	8.4716471	.001644737
609	370,881	225,866,529	24.6779254	8.4762892	.001642036
610	372,100	226,981,000	24.6981781	8.4809261	.001639344
611	373,321	228,099,131	24.7184142	8.4855579	.001636661
612	374,544	229,220,928	24.7386338	8.4901848	.001633987
613	375,769	230,346,397	24.7588368	8.4948065	.001631321
614	376,996	231,475,544	24.7790234	8.4994233	.001628664
615	378,225	232,608,375	24.7991935	8.5040350	.001626016
616	379,456	233,744,896	24.8193473	8.5086417	.001623377
617	380,689	234,885,113	24.8394847	8.5132435	.001620746
618	381,924	236,029,032	24.8596058	8.5178403	.001618123
619	383,161	237,176,659	24.8797106	8.5224321	.001615509
620	384,400	238,328,000	24.8997992	8.5270189	.001612903
621	385,641	239,483,061	24.9198716	8.5316009	.001610306
622	386,884	240,641,848	24.9399278	8.5361780	.001607717
623	388,129	241,804,367	24.9599679	8.5407501	.001605136
624	389,376	242,970,624	24.9799920	8.5453173	.001602564
625	390,625	244,140,625	25.0000000	8.5498797	.001600000
626	391,876	245,314,376	25.0199920	8.5544372	.001597444
627	393,129	246,491,883	25.0399681	8.5589899	.001594896
628	394,384	247,573,152	25.0599282	8.5635377	.001592357
629	395,641	248,858,189	25.0798724	8.5680807	.001589825
630	396,900	250,047,000	25.0998008	8.5726189	.001587302
631	398,161	251,239,591	25.1197134	8.5771523	.001584786
632	399,424	252,435,968	25.1396102	8.5816809	.001582278
633	400,689	253,636,137	25.1594913	8.5862047	.001579779
634	401,956	254,840,104	25.1793566	8.5907238	.001577287
635	403,225	256,047,875	25.1992063	8.5952380	.001574803
636	404,496	257,259,456	25.2190404	8.5997476	.001572327
637	405,769	258,474,853	25.2388589	8.6042525	.001569859
638	407,044	259,694,072	25.2586619	8.6087526	.001567398
639	408,321	260,917,119	25.2784493	8.6132480	.001564945
640	409,600	262,144,000	25.2982213	8.6177388	.001562500
641	410,881	263,374,721	25.3179778	8.6222248	.001560062
642	412,164	264,609,288	25.3377189	8.6267063	.001557632
643	413,449	265,847,707	25.3574447	8.6311830	.001555210
644	414,736	267,089,984	25.3771551	8.6356551	.001552795
645	416,025	268,336,125	25.3968502	8.6401226	.001550388
646	417,316	269,586,136	25.4165301	8.6445855	.001547988
647	418,609	270,840,023	25.4361947	8.6490437	.001545595
648	419,904	272,097,792	25.4558441	8.6534974	.001543210
649	421,201	273,359,449	25.4754784	8.6579465	.001540832
650	422,500	274,625,000	25.4950976	8.6623911	.001538462

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
651	423,801	275,894,451	25.5147016	8.6668310	.001536098
652	425,104	277,167,808	25.5342907	8.6712665	.001533742
653	426,409	278,445,077	25.5538647	8.6756974	.001531394
654	427,716	279,726,264	25.5734237	8.6801237	.001529052
655	429,025	281,011,375	25.5929678	8.6845456	.001526718
656	430,336	282,300,416	25.6124969	8.6889630	.001524390
657	431,649	283,593,393	25.6320112	8.6933759	.001522070
658	432,964	284,890,312	25.6515107	8.6977843	.001519757
659	434,281	286,191,179	25.6709953	8.7021882	.001517451
660	435,600	287,496,000	25.6904652	8.7065877	.001515152
661	436,921	288,804,781	25.7099203	8.7109827	.001512859
662	438,244	290,117,528	25.7293607	8.7153734	.001510574
663	439,569	291,434,247	25.7487864	8.7197596	.001508296
664	440,896	292,754,944	25.7681975	8.7241414	.001506024
665	442,225	294,079,625	25.7875939	8.7285187	.001503759
666	443,556	295,408,296	25.8069758	8.7328918	.001501502
667	444,889	296,740,963	25.8263431	8.7372604	.001499250
668	446,224	298,077,632	25.8456960	8.7416246	.001497006
669	447,561	299,418,309	25.8650343	8.7459846	.001494768
670	448,900	300,763,000	25.8843582	8.7503401	.001492537
671	450,241	302,111,711	25.9036677	8.7546913	.001490313
672	451,584	303,464,448	25.9229628	8.7590383	.001488095
673	452,929	304,821,217	25.9422435	8.7633809	.001485884
674	454,276	306,192,024	25.9615100	8.7677192	.001483680
675	455,625	307,546,875	25.9807621	8.7720532	.001481481
676	456,976	308,915,776	26.0000000	8.7763830	.001479290
677	458,329	310,288,733	26.0192237	8.7807084	.001477105
678	459,684	311,665,752	26.0384331	8.7850296	.001474926
679	461,041	313,046,839	26.0576284	8.7893466	.001472754
680	462,400	314,432,000	26.0768096	8.7936593	.001470588
681	463,761	315,821,241	26.0959767	8.7979679	.001468429
682	465,124	317,214,568	26.1151297	8.8022721	.001466276
683	466,489	318,611,987	26.1342687	8.8065722	.001464129
684	467,856	320,013,504	26.1533937	8.8108681	.001461988
685	469,225	321,419,125	26.1725047	8.8151598	.001459854
686	470,596	322,828,856	26.1916017	8.8194474	.001457726
687	471,969	324,242,703	26.2106848	8.8237307	.001455604
688	473,344	325,660,672	26.2297541	8.8280099	.001453488
689	474,721	327,082,769	26.2488095	8.8322850	.001451379
690	476,100	328,509,000	26.2678511	8.8365559	.001449275
691	477,481	329,939,371	26.2868789	8.8408227	.001447178
692	478,864	331,373,888	26.3058929	8.8450854	.001445087
693	480,249	332,812,557	26.3248932	8.8493440	.001443001
694	481,636	334,255,384	26.3438797	8.8535985	.001440922
695	483,025	335,702,375	26.3628527	8.8578489	.001438849
696	484,416	337,153,536	26.3818119	8.8620952	.001436782
697	485,809	338,608,873	26.4007576	8.8663375	.001434720
698	487,204	340,068,392	26.4196896	8.8705757	.001432665
699	488,601	341,532,099	26.4386081	8.8748099	.001430615
700	490,000	343,000,000	26.4575131	8.8790400	.001428571

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
701	491,401	344,472,101	26.4764046	8.8832661	.001426534
702	492,804	345,948,408	26.4952826	8.8874882	.001424501
703	494,209	347,428,927	26.5141472	8.8917063	.001422475
704	495,616	348,913,664	26.5329983	8.8959204	.001420455
705	497,025	350,402,625	26.5518361	8.9001304	.001418440
706	498,436	351,895,816	26.5706605	8.9043366	.001416431
707	499,849	353,393,243	26.5894716	8.9085387	.001414427
708	501,264	354,894,912	26.6082694	8.9127369	.001412429
709	502,681	356,400,829	26.6270539	8.9169311	.001410437
710	504,100	357,911,000	26.6458252	8.9211214	.001408451
711	505,521	359,425,431	26.6645833	8.9253078	.001406470
712	506,944	360,944,128	26.6833281	8.9294902	.001404494
713	508,369	362,467,097	26.7020598	8.9336687	.001402525
714	509,796	363,994,344	26.7207784	8.9378433	.001400560
715	511,225	365,525,875	26.7394839	8.9420140	.001398601
716	512,656	367,061,696	26.7581763	8.9461809	.001396648
717	514,089	368,601,813	26.7768557	8.9503438	.001394700
718	515,524	370,146,232	26.7955220	8.9545029	.001392758
719	516,961	371,694,959	26.8141754	8.9586581	.001390821
720	518,400	373,248,000	26.8328157	8.9628095	.001388889
721	519,841	374,805,361	26.8514432	8.9669570	.001386963
722	521,284	376,367,048	26.8700577	8.9711007	.001385042
723	522,729	377,933,067	26.8886593	8.9752406	.001383126
724	524,176	379,503,424	26.9072481	8.9793766	.001381215
725	525,625	381,078,125	26.9258240	8.9835089	.001379310
726	527,076	382,657,176	26.9443872	8.9876373	.001377410
727	528,529	384,240,583	26.9629375	8.9917620	.001375516
728	529,984	385,828,352	26.9814751	8.9958829	.001373626
729	531,441	387,420,489	27.0000000	9.0000000	.001371742
730	532,900	389,017,000	27.0185122	9.0041134	.001369863
731	534,361	390,617,891	27.0370117	9.0082229	.001367989
732	535,824	392,223,168	27.0554985	9.0123288	.001366120
733	537,289	393,832,837	27.0739727	9.0164309	.001364256
734	538,756	395,446,904	27.0924344	9.0205293	.001362398
735	540,225	397,065,375	27.1108834	9.0246239	.001360544
736	541,696	398,688,256	27.1293199	9.0287149	.001358696
737	543,169	400,315,553	27.1477439	9.0328021	.001356852
738	544,644	401,947,272	27.1661554	9.0368857	.001355014
739	546,121	403,583,419	27.1845544	9.0409655	.001353180
740	547,600	405,224,000	27.2029410	9.0450417	.001351351
741	549,081	406,869,021	27.2213152	9.0491142	.001349528
742	550,564	408,518,488	27.2396769	9.0531831	.001347709
743	552,049	410,172,407	27.2580263	9.0572482	.001345895
744	553,536	411,830,784	27.2763634	9.0613098	.001344086
745	555,025	413,493,625	27.2946881	9.0653677	.001342282
746	556,516	415,160,936	27.3130006	9.0694220	.001340483
747	558,009	416,832,723	27.3313007	9.0734726	.001338688
748	559,504	418,508,992	27.3495887	9.0775197	.001336898
749	561,001	420,189,749	27.3678644	9.0815631	.001335113
750	562,500	421,875,000	27.3861279	9.0856030	.001333333

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
751	564,001	423,564,751	27.4043792	9.0896392	.001331558
752	565,504	425,259,008	27.4226184	9.0936719	.001329787
753	567,009	426,957,777	27.4408455	9.0977010	.001328021
754	568,516	428,661,064	27.4590604	9.1017265	.001326260
755	570,025	430,368,875	27.4772633	9.1057485	.001324503
756	571,536	432,081,216	27.4954542	9.1097669	.001322751
757	573,049	433,798,093	27.5136330	9.1137818	.001321004
758	574,564	435,519,512	27.5317998	9.1177931	.001319261
759	576,081	437,245,479	27.5499546	9.1218010	.001317523
760	577,600	438,976,000	27.5680975	9.1258053	.001315789
761	579,121	440,711,081	27.5862284	9.1298061	.001314060
762	580,644	442,450,728	27.6043475	9.1338034	.001312336
763	582,169	444,194,947	27.6224546	9.1377971	.001310616
764	583,696	445,943,744	27.6405499	9.1417874	.001308901
765	585,225	447,697,125	27.6586334	9.1457742	.001307190
766	586,756	449,455,096	27.6767050	9.1497576	.001305483
767	588,289	451,217,663	27.6947648	9.1537375	.001303781
768	589,824	452,984,832	27.7128129	9.1577139	.001302083
769	591,361	454,756,609	27.7308492	9.1616869	.001300390
770	592,900	456,533,000	27.7488739	9.1656565	.001298701
771	594,441	458,314,011	27.7668868	9.1696225	.001297017
772	595,984	460,099,648	27.7848880	9.1735852	.001295337
773	597,529	461,889,917	27.8028775	9.1775445	.001293661
774	599,076	463,684,824	27.8208555	9.1815003	.001291990
775	600,625	465,484,375	27.8388218	9.1854527	.001290323
776	602,176	467,288,576	27.8567766	9.1894018	.001288660
777	603,729	469,097,433	27.8747197	9.1933474	.001287001
778	605,284	470,910,952	27.8926514	9.1972897	.001285347
779	606,841	472,729,139	27.9105715	9.2012286	.001283697
780	608,400	474,552,000	27.9284801	9.2051641	.001282051
781	609,961	476,379,541	27.9463772	9.2090962	.001280410
782	611,524	478,211,768	27.9642629	9.2130250	.001278772
783	613,089	480,048,687	27.9821372	9.2169505	.001277139
784	614,656	481,890,304	28.0000000	9.2208726	.001275510
785	616,225	483,736,625	28.0178515	9.2247914	.001273885
786	617,796	485,587,656	28.0356915	9.2287068	.001272265
787	619,369	487,443,403	28.0535203	9.2326189	.001270648
788	620,944	489,303,872	28.0713377	9.2365277	.001269036
789	622,521	491,169,069	28.0891438	9.2404333	.001267427
790	624,100	493,039,000	28.1069386	9.2443355	.001265823
791	625,681	494,913,671	28.1247222	9.2482344	.001264223
792	627,264	496,793,088	28.1424946	9.2521300	.001262626
793	628,849	498,677,257	28.1602557	9.2560224	.001261034
794	630,436	500,566,184	28.1780056	9.2599114	.001259446
795	632,025	502,459,875	28.1957444	9.2637973	.001257862
796	633,616	504,358,336	28.2134720	9.2676798	.001256281
797	635,209	506,261,573	28.2311884	9.2715592	.001254705
798	636,804	508,169,592	28.2488938	9.2754352	.001253133
799	638,401	510,082,399	28.2665881	9.2793081	.001251564
800	640,000	512,000,000	28.2842712	9.2831777	.001250000

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
801	641,601	513,922,401	28.3019434	9.2870440	.001248439
802	643,204	515,849,608	28.3196045	9.2909072	.001246883
803	644,809	517,781,627	28.3372546	9.2947671	.001245330
804	646,416	519,718,464	28.3548938	9.2986239	.001243781
805	648,025	521,660,125	28.3725219	9.3024775	.001242236
806	649,636	523,606,616	28.3901391	9.3063278	.001240695
807	651,249	525,557,943	28.4077454	9.3101750	.001239157
808	652,864	527,514,112	28.4253408	9.3140190	.001237624
809	654,481	529,475,129	28.4429253	9.3178599	.001236094
810	656,100	531,441,000	28.4604989	9.3216975	.001234568
811	657,721	533,411,731	28.4780617	9.3255320	.001233046
812	659,344	535,387,328	28.4956137	9.3293634	.001231527
813	660,969	537,367,797	28.5131549	9.3331916	.001230012
814	662,596	539,353,144	28.5306852	9.3370167	.001228501
815	664,225	541,343,375	28.5482048	9.3408386	.001226994
816	665,856	543,338,496	28.5657137	9.3446575	.001225490
817	667,489	545,338,513	28.5832119	9.3484731	.001223990
818	669,124	547,343,432	28.6006993	9.3522857	.001222494
819	670,761	549,353,259	28.6181760	9.3560952	.001221001
820	672,400	551,368,000	28.6356421	9.3599016	.001219512
821	674,041	553,387,661	28.6530976	9.3637049	.001218027
822	675,684	555,412,248	28.6705424	9.3675051	.001216545
823	677,329	557,441,767	28.6879766	9.3713022	.001215067
824	678,976	559,476,224	28.7054002	9.3750963	.001213592
825	680,625	561,515,625	28.7228132	9.3788873	.001212121
826	682,276	563,559,976	28.7402157	9.3826752	.001210654
827	683,929	565,609,283	28.7576077	9.3864600	.001209190
828	685,584	567,663,552	28.7749891	9.3902419	.001207729
829	687,241	569,722,789	28.7923601	9.3940206	.001206273
830	688,900	571,787,000	28.8097206	9.3977964	.001204819
831	690,561	573,856,191	28.8270706	9.4015691	.001203369
832	692,224	575,930,368	28.8444102	9.4053387	.001201923
833	693,889	578,009,537	28.8617394	9.4091054	.001200480
834	695,556	580,093,704	28.8790582	9.4128690	.001199041
835	697,225	582,182,875	28.8963666	9.4166297	.001197605
836	698,896	584,277,056	28.9136646	9.4203873	.001196172
837	700,569	586,376,253	28.9309523	9.4241420	.001194743
838	702,244	588,480,472	28.9482297	9.4278936	.001193317
839	703,921	590,589,719	28.9654967	9.4316423	.001191895
840	705,600	592,704,000	28.9827535	9.4353880	.001190476
841	707,281	594,823,321	29.0000000	9.4391307	.001189061
842	708,964	596,947,688	29.0172363	9.4428704	.001187648
843	710,649	599,077,107	29.0344623	9.4466072	.001186240
844	712,336	601,211,584	29.0516781	9.4503410	.001184834
845	714,025	603,351,125	29.0688837	9.4540719	.001183432
846	715,716	605,495,736	29.0860791	9.4577999	.001182033
847	717,409	607,645,423	29.1032644	9.4615249	.001180638
848	719,104	609,800,192	29.1204396	9.4652470	.001179245
849	720,801	611,960,049	29.1376046	9.4689661	.001177856
850	722,500	614,125,000	29.1547595	9.4726824	.001176471

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
851	724,201	616,295,051	29.1719043	9.4763957	.001175088
852	725,904	618,470,208	29.1890390	9.4801061	.001173709
853	727,609	620,650,477	29.2061637	9.4838136	.001172333
854	729,316	622,835,864	29.2232784	9.4875182	.001170960
855	731,025	625,026,375	29.2403830	9.4912200	.001169591
856	732,736	627,222,016	29.2574777	9.4949188	.001168224
857	734,449	629,422,793	29.2745623	9.4986147	.001166861
858	736,164	631,628,712	29.2916370	9.5023078	.001165501
859	737,881	633,839,779	29.3087018	9.5059980	.001164144
860	739,600	636,056,000	29.3257566	9.5096854	.001162791
861	741,321	638,277,381	29.3428015	9.5133699	.001161440
862	743,044	640,503,928	29.3598365	9.5170515	.001160093
863	744,769	642,735,647	29.3768616	9.5207303	.001158749
864	746,496	644,972,544	29.3938769	9.5244063	.001157407
865	748,225	647,214,625	29.4108823	9.5280794	.001156069
866	749,956	649,461,896	29.4278779	9.5317497	.001154734
867	751,689	651,714,363	29.4448637	9.5354172	.001153403
868	753,424	653,972,032	29.4618397	9.5390818	.001152074
869	755,161	656,234,909	29.4788059	9.5427437	.001150748
870	756,900	658,503,000	29.4957624	9.5464027	.001149425
871	758,641	660,776,311	29.5127091	9.5500589	.001148106
872	760,384	663,054,848	29.5296461	9.5537123	.001146789
873	762,129	665,338,617	29.5465734	9.5573630	.001145475
874	763,876	667,627,624	29.5634910	9.5610108	.001144165
875	765,625	669,921,875	29.5803989	9.5646559	.001142857
876	767,376	672,221,376	29.5972972	9.5682982	.001141553
877	769,129	674,526,133	29.6141858	9.5719377	.001140251
878	770,884	676,836,152	29.6310648	9.5755745	.001138952
879	772,641	679,151,439	29.6479342	9.5792085	.001137656
880	774,400	681,472,000	29.6647939	9.5828397	.001136364
881	776,161	683,797,841	29.6816442	9.5864682	.001135074
882	777,924	686,128,968	29.6984848	9.5900939	.001133787
883	779,689	688,465,387	29.7153159	9.5937169	.001132503
884	781,456	690,807,104	29.7321375	9.5973373	.001131222
885	783,225	693,154,125	29.7489496	9.6009548	.001129944
886	784,996	695,506,456	29.7657521	9.6045696	.001128668
887	786,769	697,864,103	29.7825452	9.6081817	.001127396
888	788,544	700,227,072	29.7993289	9.6117911	.001126126
889	790,321	702,595,369	29.8161030	9.6153977	.001124859
890	792,100	704,969,000	29.8328678	9.6190017	.001123596
891	793,881	707,347,971	29.8496231	9.6226030	.001122334
892	795,664	709,732,288	29.8663690	9.6262016	.001121076
893	797,449	712,121,957	29.8831056	9.6297975	.001119821
894	799,236	714,516,984	29.8998328	9.6333907	.001118568
895	801,025	716,917,375	29.9165506	9.6369812	.001117318
896	802,816	719,323,136	29.9332591	9.6405690	.001116071
897	804,609	721,734,273	29.9499583	9.6441542	.001114827
898	806,404	724,150,792	29.9666481	9.6477367	.001113586
899	808,201	726,572,699	29.9833287	9.6513166	.001112347
900	810,000	729,000,000	30.0000000	9.6548938	.001111111

TABLE 65 (*Continued*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
901	811,801	731,432,701	30.0166620	9.6584684	.001109878
902	813,604	733,870,808	30.0333148	9.6620403	.001108647
903	815,409	736,314,327	30.0499584	9.6656096	.001107420
904	817,216	738,763,264	30.0665928	9.6691762	.001106195
905	819,025	741,217,625	30.0832179	9.6727403	.001104972
906	820,836	743,677,416	30.0998339	9.6763017	.001103753
907	822,649	746,142,643	30.1164407	9.6798604	.001102536
908	824,464	748,613,312	30.1330383	9.6834166	.001101322
909	826,281	751,089,429	30.1496269	9.6869701	.001100110
910	828,100	753,571,000	30.1662063	9.6905211	.001098901
911	829,921	756,058,031	30.1827765	9.6940694	.001097695
912	831,744	758,550,528	30.1993377	9.6976151	.001096491
913	833,569	761,048,497	30.2158899	9.7011583	.001095290
914	835,396	763,551,944	30.2324329	9.7046989	.001094092
915	837,225	766,060,875	30.2489669	9.7082369	.001092896
916	839,056	768,575,296	30.2654919	9.7117723	.001091703
917	840,889	771,095,213	30.2820079	9.7153051	.001090513
918	842,724	773,620,632	30.2985148	9.7188354	.001089325
919	844,561	776,151,559	30.3150128	9.7223631	.001088139
920	846,400	778,688,000	30.3315018	9.7258883	.001086957
921	848,241	781,229,961	30.3479818	9.7294109	.001085776
922	850,084	783,777,448	30.3644529	9.7329309	.001084599
923	851,929	786,330,467	30.3809151	9.7364484	.001083424
924	853,776	788,889,024	30.3973683	9.7399634	.001082251
925	855,625	791,453,125	30.4138127	9.7434758	.001081081
926	857,476	794,022,776	30.4302481	9.7469857	.001079914
927	859,329	796,597,983	30.4466747	9.7504930	.001078749
928	861,184	799,178,752	30.4630924	9.7539979	.001077586
929	863,041	801,765,089	30.4795013	9.7575002	.001076426
930	864,900	804,357,000	30.4959014	9.7610001	.001075269
931	866,761	806,954,491	30.5122926	9.7644974	.001074114
932	868,624	809,557,568	30.5286750	9.7679922	.001072961
933	870,489	812,166,237	30.5450487	9.7714845	.001071811
934	872,356	814,780,504	30.5614136	9.7749743	.001070664
935	874,225	817,400,375	30.5777697	9.7784616	.001069519
936	876,096	820,025,856	30.5941171	9.7819466	.001068376
937	877,969	822,656,953	30.6104557	9.7854288	.001067236
938	879,844	825,293,672	30.6267857	9.7889087	.001066098
939	881,721	827,936,019	30.6431069	9.7923861	.001064963
940	883,600	830,584,000	30.6594194	9.7958611	.001063830
941	855,481	833,237,621	30.6757233	9.7993336	.001062699
942	887,364	835,896,888	30.6920185	9.8028036	.001061571
943	889,249	838,561,807	30.7083051	9.8062711	.001060445
944	891,136	841,232,384	30.7245830	9.8097362	.001059322
945	893,025	843,908,625	30.7408523	9.8131989	.001058201
946	894,916	846,590,536	30.7571130	9.8166591	.001057082
947	896,809	849,278,123	30.7733651	9.8201169	.001055966
948	898,704	851,971,392	30.7896086	9.8235723	.001054852
949	900,601	854,670,349	30.8058436	9.8270252	.001053741
950	902,500	857,375,000	30.8220700	9.8304757	.001052632

TABLE 65 (*Concluded*)

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, RECIPROCALS

N	N^2	N^3	$N^{\frac{1}{2}}$	$N^{\frac{1}{3}}$	$\frac{1}{N}$
951	904,401	860,085,351	30.8382879	9.8339238	.001051525
952	906,304	862,801,408	30.8544972	9.8373695	.001050420
953	908,209	865,523,177	30.8706981	9.8408127	.001049318
954	910,116	868,250,664	30.8868904	9.8442536	.001048218
955	912,025	870,983,875	30.9030743	9.8476920	.001047120
956	913,936	873,722,816	30.9192497	9.8511280	.001046025
957	915,849	876,467,493	30.9354166	9.8545617	.001044932
958	917,764	879,217,912	30.9515751	9.8579929	.001043841
959	919,681	881,974,079	30.9677251	9.8614218	.001042753
960	921,600	884,736,000	30.9838668	9.8648483	.001041667
961	923,521	887,503,681	31.0000000	9.8682724	.001040583
962	925,444	890,277,128	31.0161248	9.8716941	.001039501
963	927,369	893,056,347	31.0322413	9.8751135	.001038422
964	929,296	895,841,344	31.0483494	9.8785305	.001037344
965	931,225	898,632,125	31.0644491	9.8819451	.001036269
966	933,156	901,428,696	31.0805405	9.8853574	.001035197
967	935,089	904,231,063	31.0966236	9.8887673	.001034126
968	937,024	907,039,232	31.1126984	9.8921749	.001033058
969	938,961	909,853,209	31.1287648	9.8955801	.001031992
970	940,900	912,673,000	31.1448230	9.8989830	.001030928
971	942,841	915,498,611	31.1608729	9.9023835	.001029866
972	944,784	918,330,048	31.1769145	9.9057817	.001028807
973	946,729	921,167,317	31.1929479	9.9091776	.001027749
974	948,676	924,010,424	31.2089731	9.9125712	.001026694
975	950,625	926,859,375	31.2249900	9.9159624	.001025641
976	952,576	929,714,176	31.2409987	9.9193513	.001024590
977	954,529	932,574,833	31.2569992	9.9227379	.001023541
978	956,484	935,441,352	31.2729915	9.9261222	.001022495
979	958,441	938,313,739	31.2889757	9.9295042	.001021450
980	960,400	941,192,000	31.3049517	9.9328839	.001020408
981	962,361	944,076,141	31.3209195	9.9362613	.001019368
982	964,324	946,966,168	31.3368792	9.9396363	.001018330
983	966,289	949,862,087	31.3528308	9.9430092	.001017294
984	968,256	952,763,904	31.3687743	9.9463797	.001016260
985	970,225	955,671,625	31.3847097	9.9497479	.001015228
986	972,196	958,585,256	31.4006369	9.9531138	.001014199
987	974,169	961,504,803	31.4165561	9.9564775	.001013171
988	976,144	964,430,272	31.4324673	9.9598389	.001012146
989	978,121	967,361,669	31.4483704	9.9631981	.001011122
990	980,100	970,299,000	31.4642654	9.9665549	.001010101
991	982,081	973,242,271	31.4801525	9.9699095	.001009082
992	984,064	976,191,488	31.4960315	9.9732619	.001008065
993	986,049	979,146,657	31.5119025	9.9766120	.001007049
994	988,036	982,107,784	31.5277655	9.9799599	.001006036
995	990,025	985,074,875	31.5436206	9.9833055	.001005025
996	992,016	988,047,936	31.5594677	9.9866488	.001004016
997	994,009	991,026,973	31.5753068	9.9899900	.001003009
998	996,004	994,011,992	31.5911380	9.9933289	.001002004
999	998,001	997,002,999	31.6069613	9.9966656	.001001001
1000	1,000,000	1,000,000,000	31.6227766	10.0000000	.001000000

CHAPTER VII
SPECIFICATIONS

CHAPTER VII

SPECIFICATIONS

Specifications are a definite, particularized, and complete statement of the legal and engineering or technical requirements to be met in performing the work covered thereby.

The importance of having a clear, concise, and definite set of specifications is frequently minimized, especially by engineers who have not had extensive experience in carrying out important works. Even engineers of large experience sometimes minimize this important requirement because they may have been fortunate enough to carry through their work with less extensive and detail specifications, but it is probably safe to say that the importance of the latter sooner or later becomes evident.

In general, specifications, except as to the legal requirements, should not be intended as a rigid set of rules to be scrupulously followed according to the letter, but as a guide to indicate to the contractor the quantity and quality of the work that the engineer will require him to do. The language must, therefore, be definite and clear, so as to be susceptible of only one interpretation. This protects both the contractor and the engineer, for, if the contractor bids too low because of a misinterpretation of the engineer's requirements, he either loses money or the engineer must allow him additional compensation above the contract price. In either case, friction and bad feeling may ensue with resulting detriment to the work.

The specifications of the United States Reclamation Service, which have been gradually evolved during a period of twelve years' construction of important irrigation works, may well be taken as a model by irrigation engineers. Some of these specifications that have become more or less standardized are printed in the following pages, with some modifications.

The specifications given are not intended to be used without modification. There might be cases where they could be so used, but the main intention is to state the important points to

be covered rather than to state *how* they should be covered. With this information at hand it becomes a comparatively simple matter to draw up specifications adaptable to the peculiar local conditions involved, whereas, without such information, important clauses are very liable to be overlooked.

Subdivisions of Specifications.—A complete set of specifications consists of the following:

1. The advertisement.
2. Notice to bidders.
3. The proposal.
4. Guarantee of bond.
5. Statement of work to be performed.
6. General conditions, legal requirements, etc.
7. Detailed specifications.
8. Drawings.

THE ADVERTISEMENT

For public work (Federal, State, Municipal, etc.), advertising is usually required by law. Private work may or may not be advertised publicly. In any case, the value of wide publicity is evident, as by this means the greatest competition is obtained. The advertisement should state clearly, concisely, and briefly when and where bids will be received, what the work is that is to be performed, the approximate quantities involved, where the work is located, and from whom particulars may be obtained. A form commonly used by the Reclamation Service is as follows:

"Washington, D. C., ..., 19..

"Sealed proposals will be received at the office of the United States Reclamation Service at..........until 2 o'clock P.M., ..., 19..., for canal excavation and structures, involving about ....cubic yards of excavation, ... cubic yards of reinforced concrete, etc., etc. The work is situated..... ....

"For particulars, address the United States Reclamation Service,...

"(Sgd.) ...."

NOTICE TO BIDDERS

This should be placed in a conspicuous place at the beginning of the specifications. The purpose of this "notice" is to call particularly to the attention of bidders such requirements as they should take special cognizance of before preparing their bids, such as the requirement for certified check and guarantee of bond, whether bids may be submitted on portions of the work only, and any other instructions that the work in question may seem to make desirable.

A clear and concise set of instructions under the "Notice to Bidders" will frequently simplify the comparison of the bids after they have been opened and will avoid misunderstandings.

THE PROPOSAL

This is the contractor's bid, and should state what he proposes to do. The following form is used by the Reclamation Service:

"...................., 19...

"To............................

"Sir:

"Pursuant to the foregoing advertisement, the undersigned bidder proposes to do all the work and to furnish all the material as provided by the attached specifications, and binds himself on the acceptance of this proposal to execute a contract with necessary bond, of which this proposal and the said advertisement and specifications shall be a part, for performing and completing said work within the time required by the specifications and at the prices named in the specifications and in the schedules hereto annexed.

"The bidder furthermore agrees that, in case of his default in executing a contract with necessary bond, the proceeds of the check accompanying this proposal shall be and remain the property of the United States.

"Signature..........................

....

" (Corporate Seal) Address........................

"Names of individual members of firm or names and titles of all officers of corporation	....
	....
	....
	....
	....
	....
	....
	....

"Corporation organized under the laws of the State of........"

GUARANTEE OF BOND

This is a simple statement signed by a surety company or by individual bondsmen guaranteeing that bond to insure the faithful performance of the work will be furnished for the bidder if contract is awarded to him. The statement may be as follows:

"We agree to furnish bond for this bidder, as required by these specifications, in case contract is awarded to him on the basis of this proposal.

"Signatures and addresses of guarantors of bond	....
	....
	....
	........................"

WORK TO BE PERFORMED

Under this head should be stated the work that is to be done, and appropriate blanks should be provided in which the bidder can fill in his prices. The work may be listed by items with provision for a lump sum bid for each item, or it may be in the form of schedules of quantities in which the quantities of each class of work are given and blanks provided for the bidder to fill in his unit prices and total amounts. Some kinds of work, such as machinery, buildings, bridges, etc., are usually bid on by the lump sum for the entire job. Earth-work, concrete structures, etc., are not readily adapted to lump-sum bidding on account of uncertainties existing in the quantities and classifications. In such cases, it is more satisfactory to both con-

tractor and engineer to have an estimate of quantities and unit prices for each item.

The work to be performed on large jobs may be divided into a number of schedules allowing the work to be divided among a number of contractors if such procedure should seem to be economical or desirable. On large jobs this allows small, as well as large, contractors to bid and, therefore, results in keener competition.

GENERAL CONDITIONS

The following general clauses are used by the Reclamation Service in all specifications. (Paragraphs 20 to 28 inclusive are not used when they are not required, such as in specifications for furnishing machinery, cement, and other materials.) Special clauses applying exclusively to Government work and reference to Government bureaus and officers have been omitted. Some clauses and words unnecessary for private contracts have been modified or eliminated. Particular attention is called to the fact that these general clauses must be used with discretion, as they cover most of the legal requirements by which the contractor is to be bound, and it is desirable, especially on important works, to have them reviewed by a legal expert.

1. **Form of Proposal and Signature.**—The proposal shall be made on the form provided therefor and shall be enclosed in a sealed envelope marked and addressed as required in the notice to bidders. The bidder shall state in words and in figures the unit prices or the specific sums, as the case may be, for which he proposes to supply the material or machinery and perform the work required by these specifications. If the proposal is made by an individual it shall be signed with his full name, and his address shall be given; if it is made by a firm, it shall be signed with the copartnership name by a member of the firm, and the name and full address of each member shall be given; and if it is made by a corporation it shall be signed by an officer with the corporate name attested by the corporate seal, and the names and titles of all officers of the corporation shall be given. No telegraphic proposal or telegraphic modification of a proposal will be considered.

2. **Proposal.**—Blank spaces in the proposal should be properly filled. The phraseology of the proposal should not be changed, and no additions should be made to the items mentioned therein. Unauthorized conditions, limitations, or provisos attached to a proposal will render it informal and may cause its rejection. Alterations by erasure or interlineation must be explained or noted in the proposal over the signature of the bidder. If the unit price and the total amount named by a bidder for any item do not agree, the unit price alone will be considered as representing the bidder's intention. A bidder may withdraw his proposal before the expiration of the time during which proposals may be submitted, without prejudice to himself, by submitting a written request for its withdrawal to the officer who holds it. No proposals received after said time will be considered. Bidders are invited to be present at the opening of proposals. The right is reserved to reject any or all proposals, to accept one part of a proposal and reject the other, and to waive technical defects, as the interests of .... may require.

3. **Certified Check.**—Each bidder shall submit with his proposal a certified check for the sum stated in the notice to bidders, drawn to the order of .... If the bidder to whom an award is made fails or refuses to execute the required contract and bond within the time specified in paragraph 4, the proceeds of his check shall become the property of .... The proceeds of the check of the successful bidder will be returned after the execution of his contract and the approval of his bond on behalf of ....; and the proceeds of the checks of the other bidders will be returned at the expiration of .... days from the date of opening proposals, or sooner if contract is executed prior to that time.

4. **The Contract.**—The bidder to whom an award is made shall execute a written contract with .... and if bond is required furnish good and approved bond within .... days after receiving the forms of contract and bond for execution. If the bidder to whom an award is made fails to enter into a contract as herein provided, the award will be annulled, and an award may be made to the bidder whose proposal is next most

acceptable in the opinion of ....; and such bidder shall fulfill every stipulation embraced herein as if he were the party to whom the first award was made. The advertisement, notice to bidders, proposal, general conditions, and detail specifications and drawings will be incorporated in the contract. A corporation to which an award is made may be required, before the contract is finally executed, to furnish certificate of its corporate existence and evidence that the officer signing the contract for the corporation is duly authorized to do so.

5. **Contractor's Bond.**—The contractor shall furnish bond in an amount not less than .... per cent of the estimated aggregate payments to be made under the contract, conditioned upon the faithful performance by the contractor of all covenants and stipulations in the contract. If during the continuance of the contract any of the sureties die, or, in the opinion of ...., are or become irresponsible, the .... may require additional sufficient sureties, which the contractor shall furnish to the satisfaction of that officer within .... days after notice.

6. **Engineer.**—The word "engineer" used in these specifications or in the contract means .... He will be represented by assistants and inspectors authorized to act for him. On all questions concerning the acceptability of material or machinery, the classification of material, the execution of the work, conflicting interests of contractors performing related work, and the determination of costs, the decision of the engineer shall be final.

7. **Contractor.**—The word "contractor" used in these specifications or in the contract means the person, firm, or corporation with whom the contract is made by .... The contractor shall at all times be represented on the works in person or by a foreman or duly designated agent. Instructions and information given by the engineer to the contractor's foreman or agent on the work shall be considered as having been given to the contractor. When two or more contractors are engaged on installation or construction work in the same vicinity the engineer shall be authorized to direct the manner in which each shall conduct his work so far as it affects other contractors.

8. **Materials and Workmanship.**—All materials must be of the specified quality and equal to approved samples, if samples have been submitted. All work shall be done and completed in a thorough, workmanlike manner, notwithstanding any omission from these specifications or the drawings. All materials furnished and all work done must be satisfactory to the engineer. Work not in accordance with these specifications, in the opinion of the engineer, shall be made to conform thereto. Unsatisfactory material will be rejected, and, if so ordered by the engineer, shall, at the contractor's expense, be immediately removed from the vicinity of the work.

9. **Delays.**—The contractor shall receive no compensation for delays or hindrances to the work except when, in the judgment of the engineer, direct and unavoidable extra cost to the contractor is caused by the failure of the .... to provide necessary information, material, right of way, or site for installation. When such extra compensation is claimed a written statement thereof shall be presented by the contractor not later than .... days after the close of the month during which extra cost is claimed to have been incurred. Such claim, if found correct, will be approved and the decision of the engineer, whether extra cost has been incurred and the amount thereof, shall be final. If delays are caused by specific orders to stop work given by the engineer, or by the performance of extra work, or by unforeseen causes beyond the control of the contractor, or by the failure of .... to provide material or necessary instructions for carrying on the work or to provide the necessary right of way or site for installation, then such delay will entitle the contractor to an equivalent extension of time.

10. **Changes.**—The engineer may, without notice to the sureties on the contractor's bond, make such changes in the designs of materials or machinery or plans for installation or construction or in the quantities or character of the work or material required as he may deem advisable. These changes in plans for installation or construction may also include modifications of shapes and dimensions of canals, dams, and other structures, and the shifting of locations to suit conditions disclosed as work progresses. If such changes result in an increase or decrease of cost

to the contractor, the engineer will make such additions or deductions on account thereof as he may deem reasonable and proper and his action thereon shall be final. Extra work or material shall be charged for as hereinafter provided.

11. **Extra Work or Material.**—In connection with the work covered by this contract, the engineer may order work or material not covered by the specifications. Such work or material will be classed as extra work and will be ordered in writing. No extra work will be paid for unless ordered in writing. Extra work shall be charged for at actual necessary cost, as determined by the engineer, plus .... per cent for profit, superintendence, and general expenses. The actual necessary cost will include all expenditures for materials, labor, and supplies furnished by the contractor, and a reasonable allowance for the use of shop equipment where required, but will not include any allowance for office expenses, general superintendence, or other general expenses. At the end of each month the contractor shall present in writing his claims for extra work and material and, when requested by the engineer, shall furnish itemized statements of the cost and shall permit examination of accounts, bills, and vouchers relating thereto.

12. **Inspection.**—All materials furnished and work done under this contract will be subject to rigid inspection. The contractor shall furnish complete facilities, including the necessary labor for the inspection of all material and workmanship. The engineer shall have at all times access to all parts of the shop where such material under his inspection is being manufactured. Material that does not conform to the specifications, accepted through oversight or otherwise, may be rejected at any stage of the work. Whenever the contractor on installation or construction is permitted or directed to do night work or to vary the period during which work is carried on each day, he shall give the engineer due notice, so that inspection may be provided for.

13. **Errors and Omissions.**—The contractor will not be allowed to take advantage of any error or omission in these specifications. Suitable instructions will be given when such error or omission is discovered.

14. **Experience.**—Bidders, if required, shall present satisfactory evidence that they have been regularly engaged in furnishing material and machinery and constructing such work as they propose to execute, and that they are fully prepared with necessary capital, machinery, and material to begin the work promptly and to conduct it as required by these specifications.

15. **Specifications and Drawings.**—The contractor shall keep on the work a copy of the specifications and drawings and shall at all times give the engineer access thereto. Any drawings or plans listed in the detail specifications shall be regarded as part thereof and of the contract. Anything mentioned in these specifications and not shown in the drawings or shown in the drawings and not mentioned in these specifications shall be done as though shown or mentioned in both. The engineer will furnish from time to time such detail drawings, plans, profiles, and information as he may consider necessary for the contractor's guidance.

16. **Local Conditions.**—Bidders shall satisfy themselves as to local conditions affecting the work, and no information derived from the maps, plans, specifications, profiles, or drawings, or from the engineer or his assistants, will relieve the contractor from any risk or from fulfilling all of the terms of his contract. The accuracy of the interpretation of the facts disclosed by borings or other preliminary investigations is not guaranteed. Each bidder or his representative should visit the site of the work and familiarize himself with local conditions; failure to do so when intelligent preparation of bid depends on a knowledge of local conditions may be considered sufficient cause for rejecting a proposal.

17. **Data to be Furnished by the Contractor.**—The contractor shall furnish the engineer reasonable facilities for obtaining such information as he may desire respecting the character of the materials and the progress and manner of the work, including all information necessary to determine its cost, such as the number of men employed, their pay, the time during which they worked on the various classes of construction, etc.

18. **Damages.**—The contractor will be held responsible for and required to make good, at his own expense, all damage to

property caused by carelessness or neglect on the part ıtractor, his agent or employees.

ıaracter of Workmen.—The contractor shall not allow or employees to trespass on premises or lands in the f the work. None but skilled foremen and workmen mployed on work requiring special qualifications, and ıired by the engineer, the contractor shall discharge n who commits trespass or is in the opinion of the lisorderly, dangerous, insubordinate, incompetent, or objectionable.

aking Out Work.—The work to be done will be staked e contractor, who shall provide such material and give tance as may be required by the engineer.

ethods and Appliances.—The methods and appliances y the contractor shall be such as will, in the opinion of eer, secure a satisfactory quality of work and will contractor to complete the work in the time agreed at any time the methods and appliances appear inad- e engineer may order the contractor to improve their or efficiency, and the contractor shall conform to such failure of the engineer to order such improvement of r efficiency will not relieve the contractor from his to perform satisfactory work and to finish it in the d upon.

matic Conditions.—The engineer may order the con- suspend any work that may be damaged by climatic . When delay is caused by an order to suspend work account of climatic conditions that could have been foreseen the contractor will not be entitled to any of time on account of such order.

ıantities and Unit Prices.—The quantities noted in le or proposal are approximations for comparing bids, im shall be made against the United States for excess. ıcy therein, absolute or relative. Payment at the ed upon will be in full for the completed work and materials, supplies, labor, tools, machinery, and all nditures incident to satisfactory compliance with the

24. **Removal and Rebuilding of Defective Work.**—The contractor shall remove and rebuild at his own expense any part of the work that has been improperly executed, even though it has been included in the monthly estimates. If he refuses or neglects to replace such defective work, it may be replaced by .... at the contractor's expense.

25. **Protection of Work and Cleaning Up.**—The contractor shall be responsible for any material furnished him and for the care of all work until its completion and final acceptance, and he shall at his own expense replace damaged or lost material and repair damaged parts of the work, or the same may be done at his expense by .... He shall take all risks from floods and casualties and shall make no charge for detention from such causes. He may, however, be allowed a reasonable extension of time on account of such detention, subject to the conditions hereinbefore specified. The contractor shall remove from the vicinity of the completed work all plant, buildings, rubbish, unused material, concrete forms, etc., belonging to him or used under his direction during construction, and in the event of his failure to do so the same may be removed by .... at his expense.

26. **Roads and Fences.**—Roads subject to interference from the work covered by this contract shall be kept open, and the fences subject to interference shall be kept up by the contractor until the work is finished.

27. **Bench Marks and Survey Stakes.**—Bench marks and survey stakes shall be preserved by the contractor and in case of their destruction or removal by him or his employees, they will be replaced by the engineer at the contractor's expense.

28. **Sanitation.** —The engineer may establish sanitary and police rules and regulations for all forces employed under this contract; and if the contractor fails to enforce these rules the engineer may enforce them at the expense of the contractor.

DETAIL SPECIFICATIONS

The detail specifications should state in specific terms, as far as possible, the exact nature and quality of work that the contractor will be required to perform so that he will be enabled to

formulate an intelligent bid. No important requirements as far as they are known should be omitted; neither should requirements be inserted which it is not intended to enforce. The latter practice has resulted in the tendency of contractors to assume that certain requirements will not be enforced with resultant detriment to all concerned. The more thorough the understanding between the contractor and engineer before the bid is submitted, the more satisfactory will be the results.

It is not intended by the above remarks to imply that requirements established before a contract is let must be adhered to under all circumstances. It is probably safe to say that there have been few large works constructed the specifications for which did not have to be modified in certain details. There should, however, be special reasons for such modifications, and when modifications are made without such reasons there is evidence of laxity on the part of the engineer in enforcing the requirements, or his specifications must have been poorly drawn. Happily for the engineering profession, the former happens very infrequently. The latter is usually due to lack of knowledge of the work to be done or of current practice in regard thereto.

It can hardly be expected of an engineer to have a personal and detailed knowledge of the requirements of all the work coming under his supervision, and this lack of knowledge may sometimes show up in his specifications. It is customary, where the requirements in regard to details are not definitely known, to leave the specifications open on such points and to require that the contractor submit his own specifications, which shall be subject to the approval of the engineer. This also applies to detail designs. This procedure is also followed when it is intended that contractors shall submit bids on their standard goods.

The above remarks in regard to the detail specifications apply also to the drawings. Complete detail drawings are not always necessary, nor even desirable, as the details are nearly always changed after the work has gotten under way, and such detail drawings can be supplied after the contract has been let. The main thing to be kept in mind is that all items and conditions affecting the cost to the contractor of doing the work should be shown on the drawings as far as this is possible.

SPECIAL CONDITIONS

1. **Description of Work.**—..............................
2. **List of Drawings.**—

....

....

3. **Commencement, Prosecution, and Completion of Work.**—Work shall be commenced by the contractor within .... days, and shall be completed within .... days after the execution of the contract on behalf of .... The contractor shall at all times during the continuation of the contract prosecute the work with such force and equipment as, in the judgment of the engineer, are sufficient to complete it within the specified time.

4. **Failure to Complete the Work in the Time Agreed Upon.**—Should the contractor fail to complete the work or any part thereof in the time agreed upon in the contract, or in such extra time as may have been allowed for delays, a deduction of .... dollars per day for each schedule will be made for each and every day, including Sundays and holidays, that such schedule remains uncompleted after the date required for the completion. The said amounts are hereby agreed upon as liquidated damages for the loss to .... on account of all expenses due to the employment of engineers, inspectors, and other employees after the expiration of the time for completion and on account of the value of the operation of the irrigation works dependent thereon, and will be deducted from any money due the contractor under this contract, and the contractor and his sureties shall be liable for any excess.

5. **Progress Estimates and Payments.**—At the end of each calendar month the engineer will make an approximate measurement of all work done and material delivered up to that date, classified according to items named in the contract, and will make an estimate of the value of the same on the basis of the unit prices named in the contract. To the estimate made as above set forth will be added the amounts earned for extra work to the date of the progress estimate. From the total thus computed a deduction of 10 per cent will be made and from the remainder there will be further deducted any amount due to .... from the contractor for supplies or materials furnished or services

rendered and any other amounts that may be due to .... as damages for delays or otherwise under the terms of the contract. From the balance thus determined will be deducted the amount of all previous payments and the remainder will be paid to the contractor upon the approval of the accounts. The 10 per cent deducted as above set forth will become due and payable with and as a part of the final payment to be made as hereinafter provided. When the terms of the contract shall have been fully complied with to the satisfaction of the engineer and when a release of all claims against .... under or by virtue of the contract shall have been executed by the contractor, final payment will be made of any balance due, including the percentage withheld as above, or such portion thereof as may be due to the contractor.

Note.—Under the head of "Special Conditions" should also be stated any other requirements or conditions applying to the particular contract as a whole.

SPECIFICATIONS FOR CANAL EXCAVATION

1. **Classification of Excavation.**—All materials moved in the excavation of canals and for structures, and in the construction of embankments will be measured in excavation only, to the neat lines shown in the drawings or prescribed by the engineer, and will be classified for payment as follows:

Class 1.—Material that can be ploughed to a depth of six inches or more with a six-horse or six-mule team, each animal weighing not less than 1,400 pounds, attached to a suitable plough, all well handled by at least three men; also all material that is loose and can be handled in scrapers, and all detached masses of rock, not exceeding two cubic feet in volume, occurring in loose material or material that can be ploughed as specified.

Class 2.—Indurated material of all kinds that cannot be ploughed as described under Class 1, but that, when loosened by powder or other suitable means, can be removed by the use of ploughs and scrapers, and all detached masses of rock more than two and not exceeding ten cubic feet in volume.

Class 3.—All rock in place not included in Classes 1 and 2,

and all detached masses of rock exceeding ten cubic feet in volume, not included in Classes 1 and 2.

Note: The above classifications may also be used for "wet" excavation, but provision must be made for separate prices for wet excavation.

If there be required the excavation of any material which, in the opinion of the engineer, cannot properly be included in any of the above three classes, the engineer will determine the actual necessary cost of excavating and disposing of such material, and payment therefor as extra work will be made under the provisions of paragraph .... of these specifications. No additional allowance above the prices bid for the several classes of material will be made on account of any of the material being frozen. It is desired that the contractor or his representative be present during the measurement of material excavated. On written request of the contractor, made by him within ten days after the receipt of any monthly estimate, a statement of the quantities and classifications between successive stations included in said estimate will be furnished him within ten days after the receipt of such request. This statement will be considered as satisfactory to the contractor unless he files with the engineer, in writing, specific objections thereto, with reasons therefor, within ten days after receipt of said statement by the contractor or his representative on the work. Failure to file such written objection with reason therefor within said ten days shall be considered a waiver of all claims based on alleged erroneous estimate of quantities or incorrect classification of materials for the work covered by such statement.

2. **Canal Sections.**—The canal sections are shown in the drawings, but the undetermined stability of the material that will form the canal banks may make it desirable during the progress of the work to vary the slopes and dimensions dependent thereon. Increase or decrease of quantities excavated as a result of such changes shall be covered in the estimates and shall not otherwise affect the payments due to contractor, unless it is found by the engineer that the unit cost is thereby increased, in which case the engineer will estimate, and include in the amount due the contractor, the amount of such increase. The

canal shall be excavated to the full depth and width required and must be finished to the prescribed lines and grades in a workmanlike manner. Runways shall not be cut into canal slopes below the proposed water level. Earth slopes shall be neatly finished with scrapers or similar appliances. Rock bottoms and banks must show no points of rock projecting more than 0.3 foot into the prescribed section. Above the water line the rock will be allowed to stand at its steepest safe angle and no finishing will be required other than the removal of rock masses that are loose and liable to fall. Payment for excavation of canals will be made to the neat lines only as shown in the drawings or as established by the engineer.

3. **Preparation of Surfaces.**—The ground under all embankments that are to sustain water pressure, and the surface of all excavation that is to be used for embankments, shall be cleared of trees, brush, and vegetable matter of every kind. The roots shall be grubbed and burned with other combustible material that has been removed. The surface of the ground under the entire embankment shall be scored with a plough making open furrows not less than eight inches deep below the natural ground surface at intervals of not more than three feet. The cost of all work described in this paragraph shall be included in the unit prices bid for excavation.

4. **Construction of Embankments.**—Embankments built with teams and scrapers or with dump wagons shall be made in layers not exceeding twelve inches in thickness and kept as level as practicable. The travel over the embankments during construction shall be so directed as to distribute the compacting effect to the best advantage. Any additional compacting required over that produced by ordinary travel in distributing the material will be ordered in writing and paid for as extra work under the provisions of paragraph ..... Embankments shall be built to the height designated by the engineer to allow for settlement, and shall be levelled on top to a regular grade. (*Note.—If the engineer proposes to permit the use of machinery in canal excavation full specifications should be drafted in each individual case. Machine-built embankments must generally be rolled to make them equal in value to team-built embankments and, in order to be eco-*

nomical, machine-work should be several cents cheaper per cubic yard than team-work.) No embankments shall be made from frozen materials nor on frozen surfaces. Should the engineer direct that unsuitable material be excavated and removed from the site of any embankment, the material thus excavated will be paid for as excavation. When canal excavation precedes the building of structures, openings shall be left in the embankments at the sites of these structures, and, except when the construction of the structures is included in the contract, the contractor will not be required to complete such omitted embankments. The cost of all work described in this paragraph, except as herein specified, shall be included in the prices bid for excavation.

5. **Disposal of Materials.**—All suitable material excavated in the construction of canals and structures, or so much thereof as may be needed, shall be used in the construction of embankments and in backfilling around structures. Where the canal is on sloping ground, all material taken from the excavation shall be deposited on the lower side of the canal unless otherwise shown in the drawings or directed by the engineer. Where the canal is on level or nearly level ground, the material from the excavation shall be deposited in embankments on both sides to form the top portions of the waterway. If there is an excess of material in excavation, it shall be used to strengthen the embankment on either side of the canal as may be directed by the engineer. Material taken from cuts that is not suitable for embankment construction and surplus material may be wasted on the right of way owned by ...., at such points as shall be approved by the engineer. Unless otherwise shown in the drawings or directed by the engineer, no material shall be wasted in drainage channels, nor within .... feet of the edge of the prescribed or actual canal cut. On side-hill locations all material wasted shall be placed on the lower side of the canal unless specific written authority is obtained from the engineer to waste such material elsewhere. Waste banks shall be left with reasonably even and regular surfaces. Whenever directed by the engineer, materials found in the excavation, such as sand, gravel, or stone, that are suitable for use in structures or that are otherwise re-

quired for special purposes, shall be preserved and laid aside in some convenient place designated by him.

6. **Borrow Pits.**—Where the canal excavation at any section does not furnish sufficient suitable material for embankments, the engineer will designate where additional material shall be procured. Unless otherwise shown on the drawings or directed by the engineer a berm of fifteen feet shall be left between the outside toe of the embankment and the edge of the borrow pit, with provision for a side slope of one and one-half to one to the bottom of the borrow pit. Borrowed material will be measured in excavation only, and unless the engineer gives the contractor specific written orders to excavate other than class 1 material from borrow pits, all material obtained from this source will be paid for at the unit price bid for class 1 excavation, regardless of its actual character. Payment for excavation from borrow pits will be made for only such quantities as are required for embankments or backfilling or such as by direction of the engineer are excavated and wasted or laid aside.

7. **Overhaul.**—All material taken from the excavation and required for embankment or for other purposes shall be placed as directed by the engineer. The limit of free haul will be 200 feet. Necessary haul over 200 feet will be paid for at the price bid (*Note.—If it is desirable, a fixed sum should be stated for overhaul*) per cubic yard per hundred feet additional haul, but no allowance will be made for overhaul where the excavated material is wasted, except where such overhaul is specifically ordered in writing by the engineer. Where material is taken from borrow pits, the length of the haul will be measured along the shortest practicable route between the center of gravity of the material as found in excavation and the center of gravity of the material as deposited in each station. Where the material is taken from canal excavation, the length of the haul shall be understood to mean the distance measured along the center line of the canal from the center of gravity of the material as found in excavation to the center of gravity of the material as required to be deposited.

8. **Surface and Berm Ditches.**—If, in the judgment of the engineer, it should be necessary to construct surface and berm

drainage ditches along the lines of the canal, the contractor shall perform such work and the excavation will be paid for at the unit prices bid in the schedules covering the excavation of the canal along which such surface and berm ditches are built.

9. **Blasting.**—Any blasting that will probably injure the work will not be permitted, and any damage done to the work by blasting shall be repaired by the contractor at his expense.

SPECIFICATIONS FOR TUNNELS

1. **Excavation.**—The tunnel, shafts, and adits shall in all cases be excavated in such manner and to such dimensions as will give suitable room for the necessary timbering, lining, ventilating, pumping, and draining. The contractor shall use every reasonable precaution to avoid excavating beyond the outside lines of permanent timbering and beyond the outside neat concrete lines where no permanent timbering is required. All drilling and blasting shall be carefully and skilfully done so as not to shatter the material outside of the required lines. Any blasting that would probably injure the work will not be permitted and any damage done to the work by blasting shall be repaired by the contractor at his expense, and in a manner satisfactory to the engineer. Tunnel excavation will be paid for at the price bid per linear foot. Partial excavation, as in the case of a heading, amounting to not less than one-half the full section, will be allowed for in the monthly progress estimates at one-fourth of the price named in the contract for full excavation.

2. **Timbering.**—Suitable timbering and lagging shall be used to support the tunnel, sides, and roof wherever necessary. If practicable, this timbering may be removed before the construction of the concrete lining. Timbering may be left in place, provided it is constructed in such a manner as not to weaken the concrete lining and is in accordance with designs approved by the engineer. An approved design for such permanent timbering is shown in the drawings, but in case this design is found to be inadequate, it may be modified from time to time, subject to the approval of the engineer. Lumber for timbering shall be furnished by the contractor. The cost of furnishing and placing permanent and temporary timbering shall be included in the

price per linear foot bid in the schedule for excavating the tunnel, except that in addition thereto the contractor will be paid the sum of .... dollars per M feet B. M. for permanent timbering in place. No payment will be made for temporary timbering nor for timber used in filling cavities. In measuring permanent timbering for payment, the net length of pieces and the commercial cross-sectional dimensions will be taken. Nothing herein contained shall prevent the contractor from placing such temporary timbering as he may deem necessary nor from using heavier permanent timbering than that shown in the drawings, nor shall be construed to relieve the contractor from sole and full responsibility for the safety of the tunnel and for damage to person and property.

3. **Concrete Lining.**—The tunnel shall be lined throughout with concrete. The tunnel lining side walls and arch, where permanent timbering is not required, shall have an average thickness of .... inches, with a minimum thickness of .... inches over projecting points of rock. The average thickness of the concrete tunnel invert shall be ..... inches. Where permanent timber is required it shall be set back so far that the concrete lining will cover the timber at least .... inches. The concrete for such timbered portions of the tunnel will be estimated as having an average thickness of .... inches. If the tunnel is excavated to greater dimensions than necessary for placing the prescribed average thickness of the concrete lining, the excess space shall be solidly filled with concrete, or the lining shall be confined with forms to the prescribed thickness and properly backfilled. Concrete tunnel lining will be paid for by the cubic yard at the unit price named in the contract, measured to the neat lines shown in the drawings, based on the average thickness herein specified.

4. **Lines and Grades.**—The contractor shall provide such forms, spikes, nails, troughs for plumb-bob lines, light, etc., and such assistance as may be required by the engineer in giving lines and grades, and the engineer's marks shall be carefully preserved. Work in the shafts, adits, and tunnel shall be suspended for such reasonable time as the engineer may require to transfer lines and to mark points for line of grade. No allowance will

be made to the contractor for loss of time on account of such suspension.

5. **Draining.**—The contractor shall drain the tunnels and adits where necessary to rid the same of standing water. Pumping shall be done where gravity flow to an outlet cannot be secured.

6. **Lighting and Ventilating.**—The contractor shall properly light and ventilate the tunnel during construction.

7. **Storage and Care of Explosives.**—Caps or other exploders or fuses shall in no case be stored or kept in the same place in which dynamite or other explosives are stored. The location and design of powder magazines, methods of transporting explosives, and in general the precautions taken to prevent accidents must be satisfactory to the engineer; but the contractor shall be liable for all damages to person or property caused by blasts or explosions.

8. **Backfilling.**—Any space outside of the concrete tunnel lining shall be compactly refilled at the expense of the contractor with such of the excavated material from the tunnel as may be approved by the engineer. Large cavities in the tunnel roof may be filled with waste timber. The backfilling to the springing lines of the arch shall be placed before the arch is constructed, and shall be brought up evenly on both sides of the tunnel; it shall be spread in layers not exceeding six inches in thickness and well rammed. The invert and side walls shall be braced, if required, during the placing of the backfilling.

9. **Adits and Shafts.**—The contractor shall construct, at his own expense, such adits and shafts as he may desire to use to expedite the tunnel work. The sides and the arch of the tunnel lining situated immediately beneath the opening of each shaft shall be increased to such suitable thickness as the engineer may prescribe; and each adit shall be closed at the point where it meets the tunnel with a block of concrete averaging at least four feet in thickness, extending into the sides of the adit two feet and having a foundation two feet below the bottom of the tunnel. All concrete required for this purpose shall be furnished by the contractor at his own expense, the cement for which will be furnished to the contractor at its cost on the work. All shafts

must be completely refilled. Dumping from the top will not be allowed until the tunnel arch has been covered to a depth of at least ten feet. After the completion of the block of concrete required for closing an adit, the adit shall be refilled and the filling tamped into place for a distance of twenty feet from the tunnel.

SPECIFICATIONS FOR EXCAVATION FOR STRUCTURES

1. **Excavation.**—Unless otherwise shown in the drawings, excavation for structures will be measured for payment to lines .... outside of the foundation of the structures and to slopes of ....; provided, that, where the character of the material cut into is such that it can be trimmed to the required lines of the concrete structure and the concrete placed against the sides of the excavation without the use of intervening forms, payment for excavation will not be made outside of the required limits of the concrete. The prices bid for excavation shall include the cost of all labor and material for cofferdams and other temporary structures and of all pumping, baling, draining, and all other works necessary to maintain the excavation in good order during construction.

2. **Backfilling.**—The contractor shall place and shall compact thoroughly all backfilling around structures. The compacting must be equivalent to that obtained by the tramping of well-distributed scraper teams depositing the material in layers not exceeding six inches thick when compacted. The material used for this purpose, the amount thereof, and the manner of depositing the same must be satisfactory to the engineer. So far as practicable, the material moved in excavating for structures shall be used for backfilling, but when sufficient suitable material is not available from this source, additional material shall be obtained from borrow pits selected by the engineer. Payment for backfilling will be made at the price per cubic yard bid therefor in the schedule.

3. **Puddling.**—Backfilling and embankment around structures within .... feet of the structure shall be made with material approved by the engineer, and where practicable shall consist of sand and gravel, with an admixture of clay equal to one-fourth

to one-half the volume of the sand and gravel. The material shall be deposited in water of such depth as is approved by the engineer, unless the quantity of clay predominates, in which case the engineer may in his discretion order the material deposited in layers of six inches or less, and compacted by tamping or rolling with the smallest quantity of water that will insure consolidation. Payment for the work specified in this paragraph will be made at the unit price bid for puddling, and will be in addition to the payment made for excavation and overhaul.

4. **Blasting.**—Any blasting that will probably injure the work will not be permitted and any damage done to the work by blasting shall be repaired by the contractor at his expense.

SPECIFICATIONS FOR CONTINUOUS WOOD STAVE PIPE

1. **Description.**—The pipe shall be of the continuous-stave metal-banded type with metal tongues driven into slots in the ends of the staves to form the butt joints. The alignment and profile of the pipe are shown in the drawings. Each proposal shall be accompanied by drawings showing clearly detail dimensions of staves, bands, and tongues, which shall comply with the requirements of the specifications. Omission of drawings from proposals or any uncertainty as to detail dimensions will be sufficient cause for rejection.

2. **Material.**—All material of whatever nature required in the work shall be furnished by the contractor. The price bid for wood staves in place shall include the cost of all necessary tongues, and all royalties for special material or devices used in the pipe or in its construction. The price bid for bands in place shall include all necessary shoes and fastenings and asphaltum coating, and all royalties for special devices used in the pipe or in its construction.

3. **Diameter of Pipe.**—The inside diameter of the pipe shall be .... inches, measured after completion of the work. No diameter at any point shall differ more than 1½ per cent from the average diameter of the pipe at said point, and the average of the vertical and horizontal diameters at any point shall not be less than the specified diameter.

4. **Staves.**—All lumber used in staves shall be Douglas fir or redwood. It shall be sound, straight-grained, and free from dry-rot, checks, wind shakes, wane, and other imperfections that may impair its strength or durability. Redwood shall be clear and free from sap. In Douglas fir sap will not be allowed on more than 10 per cent of the inside face of any stave and in not more than 10 per cent of the total number of pieces; sap shall be bright and shall not occur within 4 inches of the ends of any piece; pitch seams will be permitted in not over 10 per cent of the total number of pieces, if showing on the edge only, and if not longer than 4 inches nor wider than $\frac{1}{16}$ inch; no through knots or knots at edges nor within 6 inches of ends of staves will be allowed; sound knots not exceeding $\frac{1}{2}$ inch in diameter, not falling within the above limitations, nor exceeding three within a 10-foot length will be accepted. All lumber used shall be seasoned by not less than 60 days' air drying in open piles before milling or by thorough kiln drying. All staves shall have smooth-planed surfaces and the inside and outside faces shall be accurately milled to the required circular arcs to fit a standard pattern provided by the contractor. Staves shall be trimmed perfectly square at ends and the slots for tongues shall be in exactly the same relative position for all ends and according to detail drawings furnished by the contractor. Staves shall have an average length of not less than 15 feet 6 inches and not more than 1 per cent of the staves shall have a length of less than 9 feet 6 inches. No staves shorter than 8 feet will be accepted. The finished thickness of staves shall not be less than .... inches. All staves delivered on the work in a bruised or injured condition will be rejected. If staves are not immediately used on arrival at the site of the work, they shall be kept under cover until used.

5. **Bands.**—A band shall consist of one complete fastening and shall include the bolts, shoes, nuts, and washers necessary to form same.

6. **Band Spacing.**—The distance center to center of bands shall be as marked on the profile, except that where the spacing as marked is such as to make the distances from bands to the ends of staves more than 4 inches, extra bands shall be used to keep such distances within 4 inches.

7. **Bolts.**—All bolts shall be of .... inch diameter steel and shall conform to the following specifications: (*see specifications for structural steel*). Bolts may have either button or bolt heads. They shall be at least as strong in thread as in body, and threads shall permit the nut to run freely the entire length of thread. Nuts shall be of such thickness as to insure against stripping of threads.

8. **Shoes.**—There shall be .... malleable iron shoes to each band. (*Note: It is customary to use only one shoe for pipe 48 inches and smaller in diameter and two shoes for larger sizes. For very large pipe more than two may be necessary.*) Shoes shall fit accurately to the outer surface of the pipe and shall have the dimensions shown on the drawing, or the contractor may submit for approval a drawing or sample of some other type of shoe which he may desire to furnish. If required, such shoe shall be shown under suitable test to be stronger than the bolt. The material for shoes shall conform to the following specifications: (*see standard specifications for malleable castings*).

9. **Tongues.**—Shall be of galvanized steel or iron .... inch thick and .... wide. Their length shall be such that when in place, they will penetrate into the sides of the adjacent staves without undue injury. The tongues and slots shall be so proportioned as to insure a tight fit of the tongues into the slots without danger of splitting the staves.

10. **Coating of Bands.**—The bands shall be coated by being dipped when hot in a mixture of pure California asphalt, or equivalent. Bolts shall be bent to the required arc before dipping. If the bands are dipped cold they shall be left in the hot bath a sufficient length of time to insure that they have acquired the temperature of the asphalt. This coating shall be so proportioned and applied that it will form a thick and tough coating free from tendency to flow or become brittle under the range of temperature to which it will be subjected. Where the pipe is uncovered and exposed to the full range of atmospheric temperatures, not less than 7 per cent and not more than 10 per cent of pure linseed oil shall be mixed with the asphalt.

11. **Erection.**—The pipe shall be built in a workmanlike manner. The ends of adjoining staves shall break joint at least

3 feet. The staves shall be driven in such a manner as to avoid any tendency to cause wind in the pipe and the required grade and alignment must be maintained. Staves shall be well driven to produce tight butt joints; driving bars, or other suitable means being used to avoid marring or damaging staves in driving. In rounding out the pipe, care shall be exercised to avoid damage by chisels, mauls, or other tools. The pipe shall be rounded out to produce smooth inner and outer surfaces. Bands shall be accurately spaced and placed perpendicular to the axis of the pipe. Shoes shall be placed so as to cover longitudinal joints between staves and bear equally on two staves as nearly as practicable. They shall be placed alternately on opposite sides of the pipe, so as to be out of line and cover successively on each side at least three joints. Shoes shall not be allowed to cover the butt joints. Bolts shall be hammered thoroughly into the wood to secure a bearing on 60° of the circumference of the bolt. All kinks in bolts shall be carefully hammered out. Bands shall be back-cinched to the satisfaction of the engineer so as to produce the required initial compressive stresses in the staves. All metal work shall be handled with reasonable care so as to avoid injury to the coating as much as possible. In hammering shoes into place they shall be struck so as to avoid deformation or injury. After erection the contractor shall retouch all metal work, where abraded, with an asphaltum paint satisfactory to the engineer.

12. **Painting.**—After erection and while the pipe is dry the entire outer surface shall be given a coat of refined water-gas tar, followed by a coat of refined coal-gas tar, thinned with distillate, applied with brushes or sprayed on with air pressure. Before application of the paint the surface of the pipe shall be thoroughly cleaned of dirt, dust, and foreign matter of every kind. All checks, cracks, and surface irregularities of every kind shall be thoroughly filled with paint. The finished thickness of the coating shall be not less than $\frac{1}{16}$ inch. The cost of all work under this paragraph shall be included in the price bid for pipe in place. (*Note: Redwood, not painted, is probably equal in durability to Douglas fir painted.*)

13. **Inspection.**—Final inspection of materials, as well as

erection, will be made on the work, but if the contractor so desires, preliminary inspection of staves may be made at the mill at the contractor's expense. Mill inspection, however, shall not operate to prevent the rejection of any faulty material on the work. Tests of metal work will be made at the point of manufacture by .... at ..... own expense; or they may be made at the plant by the contractor or his employees acting under the direction of the engineer or his representative; or certified tests may, at the option of the engineer, be accepted in lieu of the above-mentioned tests. The contractor shall provide, at his own expense, the necessary test pieces, and shall notify the engineer or his representatives when these pieces are ready for testing. All test bars and test pieces shall be marked so as to indicate clearly the material that they represent, and shall be properly boxed and prepared for shipment if required.

14. **Tests of Pipe.**—On completion of the work, or as soon as possible thereafter, the contractor shall make a full pressure test of the pipe. All leaks found at the time of the test shall be made tight by the contractor. If the leakage is not so large as to endanger the foundation of the pipe, the pipe shall be kept under full pressure for two days before plugging of leaks is started in order to allow the wood to become thoroughly saturated. The cost of making the test shall be borne by the contractor.

15. **Payments.**—....................................

SPECIFICATIONS FOR MANUFACTURE OF MACHINE-BANDED WOOD STAVE PIPE

1. **Description.**—The pipe shall be of the jointed, wood-stave, machine-banded type.

2. **Lengths of Pipe Sections.**—Pipe shall be furnished in lengths of 10 to 20 feet and the average length shall be not less than 16 feet. Shorter sections shall be furnished only if required for making sharp curves, in which case the lengths shall not be more than one foot shorter than will be required to keep the joint opening at the outside of the curve due to throw within a limit of $\frac{5}{16}$ inch.

3. **Material.**—All material of whatever nature required in

the manufacture of the pipe in accordance with these specifications shall be furnished by the contractor.

4. **Diameters of Pipes.**—The diameters of pipes shall be as listed in the schedules. No diameter of any pipe shall differ more than 1 per cent from the specified diameter of the pipe, and the average of the vertical and horizontal diameters at any point shall not be less than the specified diameter.

5. **Thickness of Staves.**—The finished thickness of staves shall be as follows:

4″ to 6″	1 1/16
8″ to 10″	1 1/8
12″ to 14″	1 3/16
16″ to 18″	1 1/4
20″ to 24″	1 5/16

6. **Lumber for Staves.**—All lumber used in staves shall be Douglas fir or redwood. It shall be sound, straight-grained, and free from dry-rot, checks, wind shakes, wane, and other imperfections that may impair its strength or durability. Redwood shall be clear and free from sap. In the Douglas fir sap will not be allowed on more than 10 per cent of the inside face of any stave, and in not more than 10 per cent of the total number of pieces; sap shall be bright and shall not occur within 4 inches of the ends of any piece; pitch seams will be permitted in not over 10 per cent of the total number of pieces, if showing on the edge only, and if not longer than 4 inches nor wider than 1/16 inch; no through knots nor knots at edges nor within 6 inches of ends of staves will be allowed; sound knots not exceeding 1/2 inch in diameter, not falling within the above limitations, nor exceeding three within a 10-foot length, will be accepted. All lumber used shall be seasoned by not less than sixty days' air drying in open piles before milling or by thorough kiln drying. All staves shall have smooth-planed surfaces, and the inside and outside faces shall be accurately milled to the required circular arcs.

7. **Banding.**—Size and spacing of banding wire shall be designed for a working stress of 12,000 pounds per square inch on the wire. The spacing shall in no case be greater than 4 inches, center to center of wires, nor greater than will produce a

pressure of wire on the wood of 800 pounds per square inch as calculated from the formula $B = \frac{p R f}{r (R + t)}$, where B = pressure on wood in pounds per square inch; p = water pressure in pounds per square inch; f = spacing of wire in inches; R = inside radius of pipe in inches; r = radius of wire in inches; and t = thickness of staves in inches. No wire smaller than No. 8 United States Standard gage shall be used. Wire shall be of medium steel with a tight coating of galvanizing and shall have an ultimate tensile strength of 55,000 to 65,000 pounds per square inch, and capability of being bent flat on itself without fracture. The galvanizing shall pass the standard test of four immersions in a standard solution of copper sulphate and shall show no lumps of zinc. The bidder shall state in his proposal the size of banding wire he proposes to furnish.

8. **Joints.**—Inserted joint pipe shall be furnished for diameters of 12 inches and less and for heads not exceeding 50 feet. For pipes of larger diameter than 12 inches, and for all pipes under more than 50 feet head, wood sleeve collars shall be furnished. The banding on collars shall be 50 per cent stronger than the banding on the pipe.

9. **Individual Bands.**—Individual bands shall be used on all collars for pipe 12 inches and greater in diameter. The smallest bolts used shall be ⅜ inch in diameter. The bolt shall have an ultimate tensile strength of 55,000 to 65,000 pounds per square inch; an elastic limit of one-half the ultimate tensile strength, and capability of being bent back flat on itself without fracture. The shoes shall be malleable iron, and shall be stronger than the bolts, with sufficient bearing on the wood at the tail to prevent injurious indentation in cinching. The shoes shall be sound and free from blow-holes, and shall have an ultimate tensile strength of not less than 40,000 pounds per square inch. Bidders shall submit samples or drawings of the type of shoe they propose to furnish.

10. **Coating.**—After manufacture the outside of the pipe and collars shall be dipped in a bath of hot coal tar and asphaltum. Previous to dipping the collars in coal tar and asphaltum they

shall be dipped for a depth of 1 inch at each end for a period of ten minutes in a bath of creosote. Care should be exercised to keep the coal tar and asphaltum from the tenon ends and inside surfaces, and, if necessary, the tenons shall be wrapped with paper while being dipped. After dipping, the pipe and collars shall be rolled in fine sawdust while the coating is still soft.

11. **Inspection.**—Inspection of pipe will be made at the mill, but the manufacturer will be held responsible for any damage in transit caused by improper loading of the pipe.

12. **Marking.**—Each section of pipe shall be plainly marked on the inside at one end, showing the head for which the section was wound, and the number of the banding wire used.

13. **Shipment.**—

14. **Payment.**—

SPECIFICATIONS FOR STEEL PIPE

1. **Description.**—Steel pipe may be either of the lockbar or riveted steel type. Riveted steel shall have $\left\{\begin{matrix}\text{in and out}\\ \text{taper}\end{matrix}\right\}$ courses. Circular seams may be single-riveted and longitudinal seams shall be $\left\{\begin{matrix}\text{triple}\\ \text{double}\end{matrix}\right\}$ riveted. The bidder shall submit with his bid a drawing showing details of joints, size and spacings of rivets, etc. Failure to submit such drawing will be sufficient cause for rejection of the bid.

2. **Thickness of Metal.**—The thickness of steel sheets shall be as follows:

Length, Feet	Thickness, Inches		Head, Feet
	Riveted	Lockbar	
....	....	....	....
....	....	....	....
....	....	....	....
....	....	....	....

3. **Planing and Scarfing.**—When necessary the edges of plates shall be prepared for caulking by planing and scarfing at the factory.

4. **Riveting.**—The riveting and other details of longitudinal seams shall be designed to withstand the heads given in paragraph 2. The rivets for circular joints shall be of the same size as for longitudinal seams. The intensity of working stress on rivets shall be 7,500 pounds per square inch in shear and 15,000 pounds per square inch in bearing on riveted plates. All rivet spacing shall be arranged to give the greatest possible efficiency of joint. Size of rivets and rivet spacing shall be submitted to the engineer for approval. All riveting shall be done in the field, but sufficient of the work done with different templates must be assembled at the shop to prove the work correct. (*When appropriate, shop riveting should be specified.*)

5. **Punching.**—Rivet holes may be punched and shall be no larger than is necessary to pass the required size of rivet. Drift pins shall not be used except for bringing together the several parts, and drifting with such force as to distort the holes will not be allowed. Wrongly punched plates shall not be corrected by plugging the holes and re-punching, but shall be rejected. All burrs and ragged edges on plates shall be smoothed off before the material leaves the shop. All punching shall be done at the shop before shipment.

6. **Material.**—All steel shall be made by the open-hearth process. Steel for plates shall be of the grade known as "boiler plate." Steel for rivets shall be of the grade known as "boiler rivet steel."

7. **Chemical and Physical Properties of Boiler Plate Steel.**—Boiler plate steel shall contain not more than .05 per cent phosphorus, .05 per cent sulphur, and from 0.30 to 0.60 per cent manganese. It shall show an ultimate tensile strength of 55,000 to 65,000 pounds per square inch; an elastic limit of not less than one-half the ultimate tensile strength; an ultimate elongation in 8 inches of not less than 1,500,000 divided by the ultimate tensile strength; and capability of being bent, cold or quenched, 180° flat without fracture. The steel shall be in all respects such as to stand punching, caulking, and riveting without showing the

st tendency to crack. Plates shall withstand, without crack- of the material, a drift test made by driving a pin into a inch hole, enlarging same to a diameter of 1 inch. In all pects not covered in these specifications boiler plate steel ıll conform to the " Standard Specifications for Boiler Steel " the American Society for Testing Materials, adopted Aug- . 25, 1913.

8. **Chemical and Physical Properties of Rivet Steel.**—Steel rivets shall contain not more than .04 per cent of phosphorus, 5 per cent sulphur, and from 0.30 to 0.50 per cent of man- ıese. It shall show an ultimate tensile strength of 45,000 to 000 pounds per square inch; an elastic limit of not less than ɜ-half the ultimate tensile strength; an ultimate elongation in ıches of not less than 1,500,000 divided by the ultimate tensile ength, but need not exceed 30 per cent; and capability of being ıt, cold or quenched, 180° flat without fracture. Rivet rounds ıll be tested of full size as rolled. In all respects not covered these specifications steel for rivets shall conform to the "Stand- l Specifications for Boiler Rivet Steel" of the American ːiety for Testing Materials, adopted August 25, 1913.

9. **Marking.**—Each plate shall be distinctly stamped with melt or slab number. Rivet steel may be shipped in securely tened bundles with melt number stamped on a metal tag ached. Plates and other parts shall be plainly marked for ntification and assembly in the field.

10.—**Test Pieces.**—(*This paragraph should state who is to rnish test pieces, what disposition shall be made of broken test ːcimens, etc.*)

11. **Tests of Material.**—(*This paragraph should state who is make tests, at whose expense tests are to be made, etc.*)

12. **Shipment.**—

13. **Erection.**—Erection of pipe shall be commenced at the int directed by the engineer. The contractor shall haul all .terial and distribute same along the trench and shall furnish ːompressed-air plant and full equipment for air riveting, and other equipment, tools, and supplies required for the erection the pipe and completion for service. The pipe shall be care- ly caulked and painted as the work progresses. The work of

assembling, riveting, and caulking shall be done by workmen experienced in this line. Riveting shall show first-class workmanship, rivet heads shall be full and concentric with the body of the rivet, and the rivet shall completely fill the hole and thoroughly pinch the connected pieces together. Rivets that are loose or have defective heads shall be removed and other rivets substituted therefor.

14. **Painting.**—Inside and outside of pipe shall be covered with three coats of a reliable brand of asphalt paint which shall be subject to the approval of the engineer. Before painting all surfaces shall be thoroughly cleaned by scrubbing with wire brushes or other means as directed by the engineer. All riveted joints shall be painted before riveting. All paint shall be applied while the pipe is warm and thoroughly dry.

15. **Defective Work.**—The contractor shall guarantee the material and workmanship furnished by him to be free from defects of material and construction, and he shall replace free of cost to .... any material that shall develop faults during construction or tests.

16. **Test of Pipe.**—On completion of erection, or as soon as possible thereafter, the contractor shall make a full-pressure test of the pipe. The pipe shall be water-tight under this test and the contractor shall correct any defects that develop.

17. **Payments.**—

SPECIFICATIONS FOR JOINTED REINFORCED CONCRETE PIPE

1. **Description.**—The pipe shall be composed of concrete reinforced with steel rods or wire and built in vertical forms in lengths of .... feet; the sections being connected in the trench by concrete collars reinforced with steel.

2. **Diameter of Pipe.**—The inside diameter of the pipe shall be .... inches and no diameter shall differ more than 0.5 per cent from the specified diameter of the pipe. Each section of pipe shall be a true right cylinder with the plane of the ends perpendicular to the axis of the pipe.

3. **Thickness of Shell.**—The shell of the pipe shall have a thickness of .... inches which shall be uniform around the

entire circumference. In no case will a variation of more than 10 per cent from the specified thickness be allowed.

4. **Manufacture.**—The concrete shall be thoroughly mixed in a mechanical batch mixer. It shall be deposited in such a manner that no separation of ingredients will occur and suitable tools shall be used to settle the concrete thoroughly and produce smooth surfaces. Great care shall be exercised to maintain proper spacing of the reinforcing rods. No pipe shall be manufactured when the temperature of the atmosphere is above 90°, except by permission of the engineer. During manufacture the concrete and forms shall be protected from the direct rays of the sun, and thereafter the sections shall be kept covered for five days and they shall be kept moist for twenty days. Manufacture shall not be carried on in freezing weather, except in a heated enclosure, and the sections of pipe shall be prevented from freezing. Immediately after removal of the forms all defects in the surface of the concrete shall be smoothed up with a 1 to 1 mixture of cement and fine sand, especial care being taken to produce smooth interior surfaces. Forms shall not be removed in less than twenty-four hours after the concrete has been poured.

5. **Forms.**—The forms used shall be subject to the approval of the engineer. All-steel forms are preferred, but wooden forms with steel linings may be used, provided the desired results can be obtained therewith. Forms shall be strong and rigid with sufficient bracing to prevent warping in handling, or pouring concrete. They shall be provided with suitable attachments for making the joint grooves at the ends in accordance with the drawings. A sufficient number of forms shall be provided to allow the manufacture of not less than .... sections of pipe per day, or such additional number as may be necessary to complete the work within the specified time.

6. **Reinforcement.**—The transverse reinforcement shall consist of medium steel rods or wire and shall be spaced as shown on the drawings. Sufficient longitudinal reinforcement shall be used to fasten the transverse rods and hold them rigidly in place. The transverse reinforcement may be either individual rods, welded or lapped and wired at the ends for a length of 24 di-

ameters, or it may be wound in helical coils. The latter method is preferred where its use is practicable.

7. **Steel.**—Steel may be made by either the open-hearth or Bessemer process. It shall contain not more than 0.1 per cent phosphorus if made by the Bessemer process, and not more than 0.05 per cent if made by the open-hearth process. It shall have an ultimate tensile strength of 55,000 to 70,000 pounds per square inch; an elastic limit not less than 33,000 pounds per square inch; a minimum per cent of elongation in 8 inches of 1,400,000 divided by the ultimate tensile strength; and capability of being bent cold without fracture 180° around a pin having a diameter equal to the thickness of the test piece. Bars or wire will be subject to rejection if the actual weight of any lot varies more than 5 per cent over or under the theoretical weight of that lot.

8. **Concrete.**—Concrete shall be composed of cement, sand, and gravel, well mixed and brought to a proper consistency by the addition of water. The proportions will depend upon the nature of component materials and upon the head of water that the pipe will be subjected to, but will vary in general from one part cement to five parts aggregate, to one part cement to six parts aggregate. The contractor shall not be entitled to any extra compensation by reason of such variations. (*Note: If the contractor furnishes the cement this paragraph must be modified so as to provide for separate prices for different mixtures.*)

9. **Cement.**—. . . . .

10. **Sand.**—Sand for concrete shall be obtained from natural deposits. The particles shall be hard, dense, durable, non-organic rock fragments, such as will pass a ¼-inch mesh screen. The sand must be free from organic matter and must contain not more than 3 per cent of clayey material or other objectionable non-organic matter. The sand must be so graded that, when dry and well shaken, its voids will not exceed 35 per cent.

11. **Gravel.**—Gravel for concrete shall consist of hard, dense, durable rock pebbles that will pass through a . . . . inch mesh screen and that will be rejected by a ¼-inch mesh screen. (*Note: Gravel is better suited for thin-shelled reinforced concrete*

pipe on account of the greater ease with which it can be worked in around the reinforcement.)

12. **Water.**—The water used in mixing concrete shall be reasonably clean, and free from objectionable quantities of organic matter, alkali, salts, and other impurities.

13. **Mixing Concrete.**—The cement, sand, and gravel shall be so mixed and the quantities of water added shall be such as to produce a homogeneous mass of uniform consistency. Dirt and other foreign substances shall be carefully excluded. Machine mixing will be required, and the machine and its operation shall be subject to the approval of the engineer. Enough water shall be used to give the concrete a mushy consistency. If concrete is mixed in freezing weather, the sand and gravel or water shall be heated sufficiently before mixing to remove all frost.

14. **Placing Concrete.**—No concrete shall be used that has attained its initial set, and such concrete shall be immediately removed from the site of the work. No concrete shall be placed except in the presence of a duly authorized inspector.

15. **Hauling Pipe.**—In handling and hauling the sections of pipe great care shall be taken to avoid injury to the pipe, and suitable cradles shall be provided to avoid concentration of the entire weight on small areas. The sections of pipe shall be distributed along the trench as directed by the engineer. Any pipes that are seriously injured in handling or hauling will be rejected and shall be immediately removed from the site of the work or demolished, and the contractor shall replace the same with other sections of pipe having the same quantity of reinforcement.

16. **Laying Pipe.**—The sections of pipe shall be laid true to line and grade according to stakes established by the engineer and with only sufficient joint space between to allow for satisfactory caulking. Before making the joints the adjacent sections of pipe shall be firmly bedded or supported by blocks to prevent the slightest movement while the joint is being made.

17. **Joints.**—Joints may be made by sectional collars separately moulded and set in grooves in the ends of the pipe sections, or by pouring concrete on the outside of the pipe into suitable

flexible forms and at the same time pointing and smoothing off on the inside with a 1 to 1 mixture of mortar. The concrete used for joints shall be equal to or better in quality than that used for the pipe. Each joint shall be reinforced with .... steel rods, or the equivalent in area of some other form of reinforcement satisfactory to the engineer. As soon as the joint has been made it shall be covered with wet cloths and kept so covered for ten days thereafter. If desired, after the concrete has attained its final set, damp earth may be substituted for the wet cloths.

18. **Tests of Pipe.**—On completion of the work, or as soon as possible thereafter, the contractor shall make a full-pressure test of the pipe. All leaks found at the time of the test shall be made tight by the contractor. The cost of making the test shall be borne by the contractor.

19. **Measurement.**—The price bid per linear foot shall be for pipe complete in place, ready for service, and shall include all material, *except cement*, entering into or used on the work, manufacture, hauling, laying, jointing, testing, repairing leaks, etc., until final inspection and acceptance by the engineer. The number of linear feet of pipe in place will be measured along the axis of the pipe after completion.

20. **Payments.**—

SPECIFICATIONS FOR CAST-IRON PIPE

(Based on "Standard Specifications for Cast-Iron Water-Pipe" of the American Water Works Association, adopted May 12, 1908.)

1. **Description.**—The pipes shall be made with hub and spigot joints and shall conform accurately to the dimensions and weights and shall be subjected to the tests required for class .... pipe in the "Standard Specifications for Cast-Iron Water Pipe" of the American Water Works Association, adopted May 12, 1908. They shall be straight and shall be true circles in section, with their inner and outer surfaces concentric. They shall be at least 12 feet in length, exclusive of socket. In all respects not specifically mentioned herein, the pipes and their material shall conform to the above-mentioned specifications.

2. **Quality of Iron.**—All pipes shall be made of cast iron of

good quality, and of such character as shall make the metal of castings strong, tough, and of even grain, and soft enough to admit satisfactorily of drilling and cutting. The metal shall be made without any admixture of cinder iron or other inferior metal, and shall be remelted in a cupola or air furnace. Specimen bars 2 inches wide and 1 inch thick loaded at the middle of a 24-inch span shall carry a load of not less than 2,000 pounds and shall show a deflection of not less than 0.3 inch before breaking, or, if preferred, tensile tests may be made which shall show a breaking load of not less than 20,000 pounds per square inch.

3. **Test Pieces.**—(*This paragraph should state who is to furnish test pieces and how many, and what disposition is to be made of broken test specimens.*)

4. **Quality of Castings.**—The pipes shall be smooth, free from scales, lumps, blisters, blow-holes, sand-holes, and defects of every nature that unfit them for the use for which they are intended. No plugging or filling will be allowed.

5. **Casting of Pipe.**—The straight pipes shall be cast in dry sand moulds in a vertical position. Pipes 16 inches or less in diameter shall be cast with the hub end up or down as specified in the proposals. Pipes 18 inches or more in diameter shall be cast with the hub end down. The pipes shall not be stripped or taken from the pit while showing color of heat, but shall be left in the flasks for a sufficient length of time to prevent unequal contraction by subsequent exposure.

6. **Diameters.**—The diameters of the sockets and the outside diameters of the spigot ends of the pipes shall not vary from the standard dimensions by more than .06 of an inch for pipes 16 inches or less in diameter; .08 of an inch for 18-inch, 20-inch and 24-inch pipes; .10 of an inch for 30-inch, 36-inch, and 42-inch pipes; .12 of an inch for 48-inch, and .15 of an inch for 54-inch and 60-inch pipes. Especial care shall be taken to have the sockets of the required size. The sockets and spigots will be tested by circular gages and no pipe will be received that is defective in joint from any cause.

7. **Thickness.**—For pipes whose standard thickness is less than 1 inch, the thickness of metal in the body of the pipe shall not be more than .08 of an inch less than the standard thickness

and for pipes whose standard thickness is 1 inch or more, the variation shall not exceed .10 of an inch, except that for spaces not exceeding 8 inches in length in any direction, variations from the standard thickness of .02 of an inch in excess of the allowance above given shall be permitted.

8. **Weights.**—No pipe shall be accepted whose weight is more than 5 per cent less than the standard weight for pipes 16 inches or less in diameter, and 4 per cent less than the standard weight for pipes more than 16 inches in diameter, and no excess above the standard weight or more than the given percentage will be paid for. The total weight to be paid for shall not exceed for each size and class of pipe received the sum of the standard weights of the same number of pieces of the given size and class by more than 2 per cent.

9. **Coating.**—Every pipe and special casting shall be coated, inside and out, with coal-tar pitch varnish, mixed with sufficient oil to make a smooth coating, tough and tenacious when cold and not brittle nor with any tendency to scale off. Before being dipped the pipes shall be thoroughly cleaned and shall be entirely free from rust. Castings shall have a uniform temperature of 300° F. when they are put in the vat and the coating material shall be kept heated to the same temperature. Each casting shall remain in the bath at least five minutes.

10. **Marking.**—Each pipe shall have distinctly cast upon it the initials of the maker's name, and the weight and class letter shall be conspicuously painted in white on the inside of each pipe after the coating has become hard.

11. **Inspection and Tests.**—All pipes shall be subjected to a careful hammer inspection. Tests of the material will be made by .... at its own expense, or they may be made at the plant by the contractor or his employees acting under the direction of the engineer or his representative; or certified tests may, at the option of the engineer, be accepted in lieu of the above-mentioned tests.

12. **Shipment.**—

13. **Payment.**—

SPECIFICATIONS FOR METAL FLUMES

1. **Type of Flume.**—All flumes furnished under these specifications shall be made of metal and shall be of the semicircular, smooth-interior type. Bidders shall submit with their proposals a drawing or catalogue showing clearly the type of construction and detailed dimensions of the flume that they propose to furnish. Smoothness of interior surface and ease of erection will be important factors in the consideration of proposals.

2. **Dimensions and Weight of Flume.**—The assembled flume shall have an interior diameter of .... feet .... inches, and the depth shall be that of the full semicircle. The bidder shall state the weight of the completed flume per linear foot. A complete flume shall consist of sheets, carrier rods, compression bars, shoes, nuts, and washers.

3. **Thickness of Metal Sheets.**—The thickness of the metal sheets shall be sufficient to provide necessary rigidity and stiffness. The following minimum thicknesses shall be used:

No. of Flume	U. S. Standard Gage
24 to 60	22
72 to 108	20
120 to 156	18
168 to 204	16
216 and larger	14

For the larger sizes of flumes intermediate carrier rods or reinforcing ribs shall be furnished, if necessary, to maintain the true semicircular shape of the sheets when subjected to the full weight of water and the bidder shall submit a drawing or description of the method of reinforcing he proposes to use.

4. **Size of Carrier Rods and Compression Bars.**—Carrier rods shall be designed for a working stress of 8,000 pounds per square inch when subjected to the full weight of the water; provided that the smallest allowable carrier rod shall be $\frac{3}{8}$-inch in diameter, or its equivalent. Carrier rods shall be threaded at both ends and provided with nuts and washers. They shall be as strong in thread as in body. Compression bars shall be equivalent to or larger in cross-section than the corresponding carrier rods. Compression bars shall be provided with shoes for

distributing the pressures on supporting timbers. The size and shape of shoes and washers shall be such as to distribute properly the pressures on the wooden timbers supporting the flume, and the average pressure on the timbers due to the full weight of the water in the flume shall not exceed 400 pounds per square inch. All carrier rods, compression bars, shoes, nuts, and washers shall be coated before shipment by being dipped when hot in a mixture of pure California asphalt, or its equivalent; not less than 7 per cent nor more than 10 per cent of pure linseed oil shall be mixed with the asphalt. Materials for coating shall be subject to the approval of the engineer.

5. **Joints.**—The joints between successive sheets comprising the flume lining shall be designed to be rigid and water tight and shall offer the least possible obstruction to the flow of water through the flume. All necessary crimping of sheets to form the joints shall be done by the contractor.

6. **Curves.**—The metal sheets for curved flumes shall be fabricated so as to conform exactly to the degree of curvature required. The engineer will furnish the contractor a list of lengths of flumes required of each degree of curvature, and the degree of curvature shall be plainly stamped on each sheet.

7. **Materials for Sheets.**—The metal sheets shall be manufactured from steel or pure iron, and shall be galvanized. The chemical and physical properties of the allowable materials shall be as follows:

Elements Considered	Pure Iron	Open-hearth Steel	Bessemer Steel
Carbon max. per cent.....	.03	0.07 to 0.14	0.07 to 0.14
Manganese " "	.03	0.34 to 0.46	1.00
Phosphorus " "	.01	.03	.10
Sulphur " "	.03	.05	.07
Silicon " "	.01	.02	.02
Copper " "	Recorded	Recorded	Recorded
Ultimate strength........	42,000–48,000	50,000–60,000	50,000–60,000
Elastic limit.............	22,000–30,000	25,000–35,000	25,000–35,000
Minimum elongation in 8″	25 per cent	25 per cent	25 per cent

The material shall show great homogeneity of structure as exhibited by the ends of the broken test specimens.

8. Material for Compression Bars and Carrier Rods.—These shall be made of medium steel and shall have an ultimate tensile strength of 55,000 to 65,000 pounds per square inch; an elastic limit of not less than one-half of the ultimate tensile strength; a minimum per cent of elongation in 8 inches of 1,400,000 divided by the ultimate strength; a silky fracture; and capability of being bent cold without fracture 180° around a pin having a diameter equal to the thickness of the test piece.

9. Material for Shoes and Washers.—The bearing shoes and washers for compression bands and carrier rods may be made of either gray or malleable cast iron. Gray iron castings shall conform in all respects to the standard specifications for such castings adopted September 1, 1905, by the American Society for Testing Materials, except that no tensile test will be required. Malleable iron castings shall conform to the standard specifications for such castings adopted November 15, 1904, by the American Society for Testing Materials.

10. Test Pieces.—All test pieces shall be furnished by the contractor at his expense. The number and shape of test specimens for gray and malleable castings shall be as prescribed in the specifications of the American Society for Testing Materials specified in paragraph 9 hereof. For all other materials, at least one test specimen shall be taken from each melt, and where possible shall be cut from the finished material. Specimens not cut from finished material shall, in so far as possible, receive the same treatment before testing as the finished product. Tensile test pieces shall be ¾ of an inch in diameter and shall have 8 inches of gage length.

11. Inspection and Tests.—All necessary facilities and assistance for making inspection and tests shall be furnished to the engineer by the contractor at the expense of the contractor. Physical tests and chemicals analyses will be made by . . . . at its own expense; or they may be made at the factory by the contractor or his employees, acting under the direction of the engineer or his representative; or certified tests may, at the option of the engineer, be accepted in lieu of the above-mentioned tests. No material shall be shipped until all tests and final

inspection have been made, or certified tests shall have been accepted.

12. **Galvanizing.**—The metal sheets shall have a coating of tight galvanizing. The grooving for joints and bending of sheets shall be done in such a manner as to avoid any injury to galvanizing. All sheets on which the galvanizing is cracked or otherwise injured will be rejected. The galvanizing shall consist of a coating of pure zinc evenly and uniformly applied in such a manner that it will adhere firmly to the surface of the metal. Each square foot of metal sheets shall hold not less than 1½ ounces of zinc. The galvanizing shall be of such quality that clean, dry samples of the galvanized metal shall appear black and show no copper-colored spots when they are four times alternately immersed for one minute in the standard copper sulphate solution and then immediately washed in water and thoroughly dried. The coating shall fully and completely cover all surfaces of the material, and shall appear smooth and polished and be free from lumps of zinc.

13. **Shipment.**—

14. **Measurement and Payment.**—Payment will be made on the basis of the actual assembled length of flume measured along the center line and at the prices bid in the schedule.

SPECIFICATIONS FOR STEEL HIGHWAY BRIDGES

1. **Description.**—The bridge shall be of the $\left\{\begin{array}{c}\text{riveted}\\ \text{pin-connected}\end{array}\right\}$ $\left\{\begin{array}{c}\text{deck}\\ \text{through}\end{array}\right\}$ truss type, having a span, center to center of end bearings, of .... feet .... inches, and a clear width between trusses of .... feet. The bridge shall consist of .... spans.

2. **Stress Sheets and Loading.**—The bidder shall furnish with his bid a stress sheet showing the maximum stresses to which members are to be subjected, based on the following loading:

l = span in feet.
w = weight of steel per square foot of floor.

p = live load per square foot of floor.

Dead load: w = not less than the actual weight of steel.
Wooden floor = 15 pounds per square foot.

Live load: $p = 100 - \frac{l}{10}$ or a concentrated load of 30,000 pounds on two axles 8 feet center to center; with wheels spaced 6 feet center to center, and two-thirds of the load on one axle, assumed to occupy a space 16 feet in the direction of traffic by 12 feet at right angles thereto.

Impact: for chords 25 per cent of uniform live load;
for web and floor, 40 per cent of either uniform or concentrated live load.

Wind load: unloaded chord, 100 pounds per linear foot of bridge.
loaded chord, 200 pounds per linear foot of bridge.

Note.—Neither wind nor concentrated loads are assumed to act simultaneously with uniform live load.

3. **Detail Drawings.**—The contractor shall prepare all detail and shop drawings. Each proposal shall be accompanied, in addition to the stress sheets, by such general drawings of members and details as will clearly show the type of construction proposed at all points, and all items that are necessary to enable the engineer to determine the strength of all parts of the structure and whether, as a whole and in all its parts, it complies with these specifications. As soon as practicable after the award of the contract complete detail and shop drawings shall be furnished to the engineer by the contractor, and these shall receive the approval of the engineer before work is commenced. Working drawings shall be furnished in triplicate. The approval of general and working drawings shall not relieve the contractor from the responsibility of any errors therein. In case the engineer requires additional copies of drawings for use during construction or for record these shall be furnished by the contractor without charge.

4. **Unit Stresses.**—The following limiting working stresses in pounds per square inch of net cross-section shall be used:

Tension on rolled sections	16,000
Shear on rolled sections	9,000
Bearing on pins	20,000
Shear on pins	10,000
Bearing on shop rivets	20,000
Shear on shop rivets	10,000
Bearing on field rivets	15,000
Shear on field rivets	7,500
Bearing on columns	$16{,}000-70\,\frac{L}{R}$
Bearing on expansion rollers per linear inch	$500\,d$

d = *diameter of roller in inches.*
L = *unsupported length of column in inches.*
R = *least radius of gyration in inches.*

No compression member shall have an unsupported length exceeding 120 times its least radius of gyration for main members, or 140 times its least radius of gyration for laterals.

5. **Reversed Stresses.**—Members subject to reversion of stresses shall be designed to resist both tension and compression and each stress shall be increased by $\frac{8}{10}$ of the smaller stress for determining the sectional area. The connections shall be designed for the arithmetical sum of the stresses.

6. **Combined Stresses.**—Members subject to both direct and bending stresses shall be designed so that the greatest unit fiber stress shall not exceed the allowable unit stress for the member.

7. **Net Sections.**—The net section of any tension flange or member shall be determined by a plane cutting the member square across at any point. The greatest number of rivet holes that can be cut by any such plane, or whose centers come nearer than $2\frac{1}{2}$ inches to said plane, are to be deducted from the cross-section when computing the net area.

8. **Minimum Sizes.**—No metal less than $\frac{5}{16}$ inch in thickness shall be used except for filling plates. The smallest angles used shall not be less than $2\frac{1}{2} \times 2\frac{1}{2} \times \frac{5}{16}$ inches. A single angle shall never be used for a compression member.

9. **Connections.**—All connections shall be designed to de-

velop the full strength of the members. Connecting plates shall be used for connecting all members, and in no case shall any two members be connected directly by their flanges. Angles subject to tensile stress shall be connected by both legs, otherwise only the section of the leg actually connected will be considered effective.

10. **Portal Bracing.**—Portal bracing shall consist of straight members and shall be designed to transmit the full wind reaction from the upper lateral system into the end posts and abutments. The clear head room below portal and sway bracing for a width of 6 feet on either side of center line shall be not less than 15 feet.

11. **Sway Bracing.**—Sway bracing of an approved type shall be provided at each panel point.

12. **Lateral Systems.**—Upper and lower lateral systems shall be designed to resist the maximum wind pressures from either direction. The members shall be as nearly as practicable in the plane of the axes of the chords.

13. **Floor System.**—All floor beams and stringers shall be rolled or riveted steel girders. Floor beams shall be rigidly connected to the trusses and stringers shall be rigidly connected to the floor beams.

14. **Intersection of Axes of Members.**—The axes of all members of trusses, and those of lateral systems coming together at any apex of a truss or girder must intersect at a point whenever such an arrangement is practicable, otherwise all induced stresses and bend of members caused by the eccentricity must be provided for.

15. **Batten Plates and Lattice Bars.**—The open sides of compression members shall be stayed by batten plates at the ends and by diagonal lattice bars at intermediate points. Batten plates shall be used at intermediate points when, for any reason, the latticing is interrupted. Lattice bars shall be inclined to the member not less than 60° for single latticing nor less than 45° for double latticing.

16. **Eyebars.**—The thickness of eyebars shall be not less than 5/8 inch nor less than 1/7 the width of the bar. Heads of eyebars shall be formed by upsetting and forging and shall be so propor-

fitting of all parts upon assembly in the field, and, if necessary to insure this, all members shall be assembled in the shop, and fitted before shipment.

19. **Pins.**—All pins shall be turned smoothly to a gage and shall be finished perfectly round, smooth, and straight. All pins up to and including $3\frac{1}{2}$ inches in diameter shall fit the pin-holes within 1/50 inch; all pins over $3\frac{1}{2}$ inches in diameter shall fit their holes within 1/32 inch. The contractor must provide steel-pilot nuts for all pins to preserve the threads while the pins are being driven.

20. **Camber.**—All trusses shall be cambered by making the top-chord section longer than the corresponding bottom-chord section by $\frac{3}{16}$ inch for each 10 feet of length.

21. **Expansion and Contraction.**—Provision shall be made for changes in length due to temperature variations of at least $\frac{1}{8}$ inch for each 10 feet of span.

22. **Roller Ends.**—Each truss of more than 60 feet span shall be provided with one roller end. For spans 60 feet and less a sliding end may be used. Rollers shall be turned accurately to gage and must be finished perfectly round and to the correct diameter or diameters from end to end. The tongues and grooves in plates and rollers must fit snugly so as to prevent lateral motion. Roller beds must be planed. The smallest allowable diameter of expansion rollers is $3\frac{1}{2}$ inches.

23. **Anchorages.**—Every span must be anchored at each end to the pier or abutment in such a manner as to prevent lateral motion, but so as not to interfere with the longitudinal motion of the truss due to changes of temperature. The shoes or bolsters shall be so located that the anchor bolts will occupy a central position in the slotted holes at a temperature of 40° F. Bedplates shall be designed to distribute the load over a sufficient area to keep the pressure on the masonry below 400 pounds per square inch.

24. **Hand Railing.**—A suitable latticed hand railing shall be provided for each truss.

25. **Shop Painting.**—Before leaving the shop all structural steel, except as below specified, shall be thoroughly cleaned of all loose scales and rust and given one coat of good iron ore paint

mixed with pure linseed oil, which shall be well worked into all joints and open spaces. All surfaces of steel that will come in contact with each other shall be painted before being riveted or bolted together. Pins, pinholes, screw threads, and all finished surfaces shall not be painted, but shall be coated with white lead and tallow as soon as they are finished.

MATERIAL

26. **Manufacture.**—Structural steel shall be made by the open-hearth process and shall conform in all respects, not specifically mentioned herein, to the "Standard Specifications for Structural Steel for Bridges of the American Society for Testing Materials," adopted August 25, 1913.

27. **Physical and Chemical Properties of Structural Steel.**—Steel shall contain not more than 0.05 per cent sulphur, and not more than 0.04 per cent phosphorus for basic open-hearth nor more than 0.06 per cent phosphorus for acid open-hearth. It shall have an ultimate tensile strength of 55,000 to 65,000 pounds per square inch; an elastic limit as indicated by the drop of beam of not less than one-half the ultimate tensile strength; a minimum per cent of elongation in 8 inches of 1,500,000 divided by the ultimate tensile strength; a silky fracture and capability of being bent cold without fracture 180° flat on itself for material $\frac{3}{4}$ inch thick and under; for material over $\frac{3}{4}$ inch to and including $1\frac{1}{4}$ inches around a pin having a diameter equal to the thickness of the test piece; and for material over $1\frac{1}{4}$ inches thick, around a pin having a diameter equal to twice the thickness of the test piece. A deduction of 2.5 will be allowed in the specified percentage of elongation for each $\frac{1}{16}$ inch in thickness below $\frac{5}{16}$ inch and a deduction of 1 will be allowed for each $\frac{1}{8}$ inch in thickness above $\frac{3}{4}$ inch.

28. **Physical and Chemical Properties of Rivet Steel.**—Rivet steel shall contain not more than .04 per cent each of sulphur and phosphorus. It shall have an ultimate tensile strength of 45,000 to 55,000 pounds per square inch; an elastic limit as determined by the drop of beam of not less than one-half the ultimate tensile strength; a minimum per cent of elongation in 8 inches of 1,500,000 divided by the ultimate tensile strength;

a silky fracture; and capability of being bent cold without fracture 180° flat on itself.

29. **Finish.**—Finished material must be free from injurious seams, flaws, or cracks, and have a workmanlike finish.

30. **Marking.**—Every finished piece of steel shall have the melt number stamped or rolled upon it. Steel for pins and rollers shall be stamped on the end. Rivet steel and other small parts may be bundled, with the above marks on an attached metal tag.

31. **Test Pieces.** (*This paragraph should state who is to furnish test pieces and how many, and what disposition is to be made of the broken test specimens, etc.*)

32. **Tests.** (*This paragraph should state who is to make tests, at whose expense tests are to be made, etc.*)

33. **Shipment.**

34. **Payment for Fabricated Material.**—

ERECTION

35. **Material and Labor.**—The contractor shall furnish all labor, tools, machinery, and materials, except wood flooring, for erecting the bridge complete in place, including all hauling, erection, and dismantling of all falsework and staging, setting of anchor bolts, and all other work necessary for the completion of the structure ready for traffic.

36. **Wood Floor.**—Lumber for flooring shall be furnished, and put in place by the contractor and he shall furnish all necessary fastenings. Flooring shall be 4 inches thick and shall be of sound timbers of good grade, rough. A 4 x 8 inch wheel-guard shall be placed adjacent to each truss.

37. **Painting After Erection.**—After erection all metal work shall be thoroughly cleaned of mud, grease, and other objectionable matter and evenly painted with two coats of paint of the kind and colors specified by the engineer. Linseed oil shall be used as the vehicle in mixing the paint for each of these coats, and the separate coats shall have distinctly different shades of color. All recesses which might retain water shall be filled with thick paint or some water-proof material before final painting. The first coat shall be allowed to become thoroughly dry before

the second coat is applied. No painting shall be done in wet or freezing weather.

38. **Final Payment.**—

SPECIFICATIONS FOR CONCRETE

1. **Composition.**—Concrete shall be composed of cement, sand, and broken rock or clean gravel, well mixed and brought to a proper consistency by the addition of water. Ordinarily one part by volume, measured loose, of cement shall be used with ...... parts of sand and ...... parts of broken rock or gravel. These proportions may be modified by the engineer as the work or the nature of the materials used may render it desirable, and the contractor shall not be entitled to any extra compensation by reason of such modifications.

(*Note.—If the contractor furnishes the cement this paragraph must be modified to provide for different prices for different mixtures.*)

2. **Cement.** (*See specifications for cement.*)

3. **Reinforcement Bars.**—Steel bars shall be placed in the concrete wherever shown in the drawings or prescribed by the engineer. The exact position and shape of reinforcement bars are not shown in all cases in the drawings accompanying these specifications, but the contractor will be furnished supplemental detailed drawings and lists which will give him the information necessary for cutting, bending, and spacing of bars. The steel used for concrete reinforcement shall be so secured in position that it will not be displaced during the depositing of the concrete, and special care shall be exercised to prevent any disturbance of the steel in concrete that has already been placed.

4. **Sand.**—Sand for concrete may be obtained from natural deposits or may be made by crushing suitable rock. The sand particles shall be hard, dense, durable rock fragments, such as will pass a ¼-inch mesh screen. The sand must be free from organic matter and must not contain more than 5 per cent of clayey and other objectionable non-organic material. The sand must be so graded that when dry and well shaken its voids will not exceed 35 per cent.

5. **Broken Rock or Gravel.**—The broken rock or gravel for

concrete must be hard, dense, durable rock fragments or pebbles that will pass through a ....-inch mesh screen when used for plain concrete, and through a ....-inch mesh screen when used for reinforced concrete, and that will be rejected by a ¼-inch mesh screen.

6. Water.—The water used in mixing concrete must be reasonably clean and free from objectionable quantities of organic matter, alkali salts, and other impurities.

7. Mixing.—The cement, sand, and broken rock or gravel shall be so mixed and the quantities of water added shall be such as to produce a homogeneous mass of uniform consistency. Dirt and other foreign substance shall be carefully excluded. Machine mixing will be required unless specific authority to use hand mixing is given by the engineer. The machine and its operation shall be subject to the approval of the engineer. Hand mixing, if permitted, shall be thorough and shall be done on a clean, tight floor. In general, enough water shall be used in mixing to give the concrete the consistency ordinarily designated as "wet." Concrete containing a minimum amount of water, ordinarily designated as "dry" concrete, will be permitted only where the nature of the work renders the use of "wet" concrete impracticable. If concrete is mixed in freezing weather, the materials shall be heated sufficiently before mixing to remove all frost and maintain a temperature above 32° F., until the concrete has been placed in the work and has attained its final set.

8. Placing.—Concrete shall be placed in the work before the cement takes its initial set. No concrete shall be placed in water except by permission of the engineer and the method of depositing the same shall be subject to his approval. Foundation surfaces upon which concrete is to be placed must be free from mud and débris. When the placing of concrete is to be interrupted long enough for the concrete to take its final set, the working face shall be given a shape, by the use of forms or other means, at the option of the engineer, that will secure proper union with subsequent work. All concrete surfaces upon or against which concrete is to be placed and to which the new concrete is to adhere, shall be roughened, thoroughly

cleaned, and wet before the concrete is deposited. "Dry" concrete shall be deposited in layers not exceeding 6 inches in thickness, each of which shall be rammed until water appears on the surface. "Wet" concrete shall be stirred with suitable tamping bars, shovels, or forked tools until it completely fills the form, closes snugly against all surfaces, and is in perfect and complete contact with any steel used for reinforcement. Where smooth surfaces are required a suitable tool shall be worked up and down next to the form until the coarser material is forced back and a mortar layer is brought next to the form. No concrete shall be placed except in the presence of a duly authorized inspector.

9. **Finishing.**—The surface of concrete finished against forms must be smooth, free from projections, and thoroughly filled with mortar. Immediately upon the removal of forms all voids shall be neatly filled with cement mortar, irregularities in exposed surfaces shall be removed and minor imperfections of finish shall be smoothed to the satisfaction of the engineer. Exposed surfaces of concrete not finished against forms, such as horizontal or sloping surfaces, shall be brought to a uniform surface and worked with suitable tools to a smooth mortar finish. All sharp angles where required shall be rounded or bevelled by the use of moulding strips or suitable moulding or finishing tools.

10. **Protection.**—The contractor shall protect all concrete against injury. Exposed surfaces of concrete shall be protected from the direct rays of the sun and shall be kept damp for at least two weeks after the concrete has been placed. Concrete laid in cold weather shall be protected from freezing by such means as are approved by the engineer. All damage to concrete shall be repaired by the contractor at his expense, in a manner satisfactory to the engineer.

11. **Forms.**—Forms to confine the concrete and shape it to the required lines shall be used wherever necessary. Where the character of the material cut into to receive a concrete structure is such that it can be trimmed to the prescribed lines, the use of forms will not be required. The forms shall be of sufficient strength and rigidity to hold the concrete and to withstand the necessary pressure and ramming without deflection from the

prescribed lines. For concrete surfaces that will be exposed to view and for all other concrete surfaces that are to be finished smooth, the lagging of forms must be surfaced and bevel-edged or matched; provided that smooth metal forms may be used if desired. All forms shall be removed by the contractor, but not until the engineer gives permission. Forms may be used repeatedly, provided they are maintained in serviceable condition and thoroughly cleaned before being re-used.

12. **Measurement.**—Concrete will be measured for payment to the neat lines shown in the drawings or prescribed by the engineer under these specifications. No payments will be made for concrete outside of the prescribed lines.

13. **Payment.**—The unit price bid for concrete shall include all material and labor entering into its construction.

SPECIFICATIONS FOR PAVING

1. **Dry Paving.**—Where shown in the drawings and where directed by the engineer, dry paving shall be placed on the embankment slopes and on the beds and banks of canals and other watercourses. The rock used for paving shall be clean, hard, dense, and durable. The dimensions of paving stone normal to the face of the pavement shall be not less than .... inches. They shall have an average volume of not less than .... of a cubic foot, not more than 25 per cent of the pieces being less than .... of a cubic foot in volume. Either boulders or quarried rock may be used if fulfilling the requirements as to quality and dimensions. If quarried rock is used, the stones shall have roughly squared, reasonably flat, upper faces. The stones shall be bedded in a layer of sand and gravel or unscreened crushed rock, having an average thickness of not less than .... inches. They shall be hand placed with close joints to the lines and grades established by the engineer, and the spaces between the stones shall be filled with spalls and gravel or crushed rock. The thickness of the paving, including the gravel layer, shall be not less than .... inches. Payment for dry paving will be made at the unit prices per square yard bid therefor in the schedules.

2. **Grouted Paving.**—Where shown in the drawings and where directed by the engineer, grouted paving shall be placed on the

embankment slopes and on the beds and banks of canals and other watercourses. The rock used for paving shall be clean, hard, dense, and durable. The dimension of paving stones normal to the face of the pavement shall be not less than .... inches. They shall have an average volume of not less than .... of a cubic foot, not more than 25 per cent of the pieces being less than .... of a cubic foot in volume. Either boulders or quarried rock may be used if fulfilling the requirements as to quality and dimensions. If quarried rock is used, the stones shall have roughly squared, reasonably flat, upper faces. The stones shall be bedded in a layer of sand and gravel or unscreened crushed rock, having an average thickness of not less than .... inches. They shall be hand placed with close joints to the lines and grades established by the engineer and the spaces between the stones shall be filled with spalls and gravel or crushed rock, from which the sand or fine material has been removed by screening, after which a mortar, composed of three parts sand and one part cement, shall be poured into the voids so as to form a water-tight surface. After the cement mortar has been added the paving shall be kept moist for forty-eight hours after the cement has reached its permanent set. The thickness of paving, including the gravel layer, shall be not less than .... inches. Payment for grouted paving will be made at the unit prices per square yard bid therefor in the schedules.

3. **Rubble Concrete Paving.**—Where shown in the drawings and where directed by the engineer, rubble concrete paving shall be placed on the embankment slopes and on the beds and banks of canals and other watercourses. The rock used for paving shall be clean, hard, dense, and durable. The dimension of paving stones normal to the face of the paving shall be not less than .... inches. They shall have an average volume of not less than .... of a cubic foot, not more than 25 per cent of the pieces being less than .... of a cubic foot in volume. Either boulders or quarried rock may be used if fulfilling the requirements as to quality and dimensions. If quarried rock is used the stones shall have roughly squared, reasonably flat, upper faces. The paving shall have a foundation course of sand and gravel or unscreened crushed rock not less than .... inches in thickness.

Upon this foundation course shall be placed a layer of concrete .... inches thick. The paving stones shall be bedded in this concrete before the concrete has taken its initial set. The stones shall be hand placed with close joints to the lines and grades established by the engineer and the spaces between the stones shall be filled with spalls or with gravel or crushed rock from which the sand or fine material has been removed by screening, after which a mortar composed of three parts sand and one part cement shall be poured into the voids so as to form a water-tight surface. After the cement mortar has been added, the paving shall be kept moist for forty-eight hours after the cement has reached its permanent set. The thickness of paving, including the gravel layer shall be not less than .... inches. Payment for rubble-concrete paving will be made at the unit prices per square yard bid therefor in the schedule.

SPECIFICATIONS FOR CEMENT

1. **Definition.**—The cement shall be the product obtained by finely pulverized clinker produced by calcining to incipient fusion, an intimate mixture of properly proportioned argillaceous and calcareous substances, with only such additions subsequent to calcining as may be necessary to control certain properties. Such additions shall not exceed 3 per cent, by weight, of the calcined product.

2. **Composition.**—In the finished cement, the following limits shall not be exceeded:

	Per cent
Loss on ignition for 15 minutes	4
Insoluble residue	1
Sulphuric anhydride (SO_3)	1.75
Magnesia (MgO)	4

3. **Specific Gravity.**—The specific gravity of the cement shall be not less than 3.10. Should the cement as received fall below this requirement, a second test may be made upon a sample heated for thirty minutes at a very dull red heat.

4. **Fineness.**—At least 92 per cent of the cement by weight shall pass through the No. 100 sieve, and at least 75 per cent shall pass through the No. 200 sieve.

5. **Soundness.**—Pats of neat cement prepared and treated as hereinafter prescribed shall remain firm and hard and show no sign of distortion, checking, cracking, or disintegration. If the cement fails to meet the prescribed steaming test, the cement may be rejected or the steaming test repeated after seven or more days, at the option of the engineer.

6. **Time of Setting.**—The cement shall not acquire its initial set in less than forty-five minutes and must have acquired its final set within ten hours.

7. **Tensile Strength.**—Briquettes made of neat cement, after being kept in moist air for twenty-four hours and the rest of the time in water, shall develop tensile strengths per square inch as follows:

	Pounds
After seven days	500
After twenty-eight days	600

Briquettes made up of one part cement and three parts standard Ottawa sand, by weight, shall develop tensile strengths per square inch as follows:

	Pounds
After seven days	200
After twenty-eight days	275

The average of the tensile strengths developed at each age by the briquettes in any set made from one sample is to be considered the strength of the sample at that age, excluding any results that are manifestly faulty. The average strength of the sand mortar briquettes at twenty-eight days shall show an increase over the average strength at seven days.

8. **Brand.**—Bids for furnishing cement or for doing work in which cement is to be used shall state the brand of cement proposed to be furnished and the mill at which made. The right is reserved to reject any cement which has not established itself as a high-grade Portland cement, and has not been made by the same mill for two years and given satisfaction in use for at least one year under climatic and other conditions at least equal in severity to those of the work proposed.

9. **Packages.**—The cement shall be delivered in sacks, barrels, or other suitable packages (to be specified by the engineer),

and shall be dry and free from lumps. Each package shall be plainly labelled with the name of the brand and of the manufacturer. A sack of cement shall contain 94 pounds net. A barrel shall contain 376 pounds net. Any package that is short weight or broken, or that contains damaged cement, may be rejected, or accepted as a fractional package, at the option of the engineer. If the cement is delivered in cloth sacks, the sacks used shall be strong and serviceable and securely tied, and the empty sacks will, if practicable, be returned to the contractor at the point of delivery of the cement. On final settlement under the contract, ten cents will be paid the contractor for each sack furnished by him in accordance with the above requirements and not returned in serviceable condition.

10. **Inspection.**—The cement shall be tested in accordance with the standard methods hereinafter prescribed. In general the cement will be inspected and tested after delivery, but partial or complete inspection at the mill may be called for in the specifications or contract. Tests may be made to determine the chemical composition, specific gravity, fineness, soundness, time of setting, and tensile strength, and a cement may be rejected in case it fails to meet any of the specified requirements. An agent of the contractor may be present at the making of the tests or they may be repeated in his presence.

11. **Sampling.**—The selection of the samples for testing will be left to the engineer. The number of packages sampled and the quantity to be taken from each package will depend on the importance of the work, the number of tests to be made, and the facilities for making them. The samples should be so taken as to represent fairly the material, and, where conditions permit, at least one barrel in every fifty should be sampled. Before tests are made, samples shall be passed through a sieve having twenty meshes per linear inch to remove foreign material. Samples shall be tested separately for physical qualities, but for chemical analysis mixed samples may be used. Every sample should be tested for soundness, but the number of tests for other qualities will be left to the discretion of the engineer.

12. **Chemical Analysis.**—The method to be followed for the analysis of cement shall be that proposed by the Committee on

Uniformity in the Analysis of Materials for the Portland Cement Industry, reported in *The Journal of the Society for Chemical Industry*, Vol. 21, p. 12, 1902, and published in *Engineering News*, Vol. 50, p. 60, 1903, and in *The Engineering Record*, Vol. 48, p. 49, 1903. The insoluble residue shall be determined on a 1-gram sample, which is digested on the steam bath in hydrochloric acid of approximately 1.035 specific gravity until the cement is dissolved. The residue is filtered, washed with hot water, and the filter-paper contents digested on the steam bath in a 5-per-cent solution of sodium carbonate. The residue is then filtered, washed with hot water, then with hot hydrochloric acid, approximately of 1.035 specific gravity, and finally with hot water, then ignited and weighed. The quantity so obtained is the insoluble residue.

13. Determination of Specific Gravity.—The determination of specific gravity may be made with a standardized apparatus of Le Chatelier or other equally accurate form. Benzine (62° Baumé naphtha), or kerosene free from water, should be used in making the determination. The cement should be allowed to pass slowly into the liquid of the volumenometer, taking care that the powder does not adhere to the sides of the graduated tube above the liquid and that the funnel through which it is introduced does not touch the liquid. The temperature of the liquid in the flask should not vary more than 1° F. during the operation. To this end the flask should be immersed in water. The results of repeated tests should agree within 0.01.* If the specific gravity of the cement as received is less than 3.10, a redetermination may be made as follows: Seventy grams of the cement is placed in a nickel or platinum crucible about 2 inches in diameter and heated for thirty minutes

* Under the metric system the specific gravity of a solid is expressed mathematically by the weight in grams of 1 cubic centimeter of the substance of the solid. Therefore, in using a volumenometer graduated to show volume, or displacement, in cubic centimeters:

$$\text{Specific gravity} = \frac{\text{Weight of substance used, in grams}}{\text{Displacement in cubic centimeters.}}$$

In the standard Le Chatelier volumenometer 64 grams of Portland cement are taken.

at a temperature between 419° C. and 630° C. After the cement has cooled to atmospheric temperature the specific gravity shall be determined in the same manner as described above. The cement should be heated in a muffle or other suitable furnace, the temperature of which is to be maintained above the melting point of zinc (419° C.) but below the melting point of antimony 630° C.). This maximum temperature can be recognized as a very dull red which is just discernible in the dark.

14. **Determination of Fineness.**—The No. 100 and No. 200 sieves shall conform to the standard sieve specifications of the Bureau of Standards, Department of Commerce. The determination of fineness should be made on a 50-gram sample, which may be dried at a temperature of 100° C. (212° F.), prior to sifting. The coarsely screened sample should be weighed and placed on the No. 200 sieve, which, with the pan and cover attached, should be held in one hand in a slightly inclined position and moved forward and backward in the plane of inclination, at the same time striking the side gently about 200 times per minute against the palm of the other hand on the upstroke. The operation is to be continued until not more than 0.05 gram will pass through in one minute. The residue should be weighed, then placed on the No. 100 sieve, and the operation repeated. The sieves should be thoroughly dry and clean. Determination of fineness may be made by washing the cement through the sieve or by a mechanical sifting device which has been previously standardized with the results obtained by hand sifting on equivalent samples. In case of the failure of the cement to pass the fineness requirements by the washing method or the mechanical device, it shall be tested by hand.

15. **Mixing Cement Pastes and Mortars.**—The quantity of cement or cement and sand to be used in the paste or mortar should be expressed in grams and the quantity of water in cubic centimeters. The material should be weighed, placed upon a non-absorbent surface, thoroughly mixed dry if sand be used, and a crater formed in the center, into which the proper percentage of clean water should be poured; the material on the outer edge should be turned into the crater by the aid of a trowel. As soon as the water has been absorbed, the operation should be completed

by vigorously mixing with the hands for one minute and a half. During the operation of mixing, the hands should be protected by rubber gloves. The temperature of the room and the mixing water should be maintained as nearly as practicable at 21° C. (70° F.).

16. **Determination of Normal Consistency.**—The normal consistency for neat paste to be used in making briquettes and pats should be determined by the ball method, as follows: A quantity of cement paste should be mixed in the manner described in paragraph 15, and quickly formed into a ball about 2 inches in diameter. The ball should then be dropped upon a hard, smooth, and flat surface from a height of 2 feet. The paste is of normal consistency when the ball does not crack and does not flatten more than one-half of its original diameter. Trial pastes should be made with varying percentages of water, until the correct consistency is obtained. The percentage of water to be used in mixing mortars for sand briquettes is given by the formula:

$$y = 2/3 \frac{P}{n+1} + K$$

in which y is the percentage of water required for the sand mortar;

P is the percentage of water required for neat cement paste of normal consistency;

n is the number of parts of sand to one of cement by weight, and

K is a constant which for standard Ottawa sand has the value of 6.5.

The percentage of water to be used for mortars containing three parts standard Ottawa sand, by weight, to one of cement is indicated in the following statement:

Percentage of Water for Neat Cement Paste	Percentage of Water for 1 to 3 Mortars of Standard Ottawa Sand	Percentage of Water for Neat Cement Paste	Percentage of Water for 1 to 3 Mortars of Standard Ottawa Sand
18	9.5	24	10.5
19	9.7	25	10.7
20	9.8	26	10.8
21	10.0	27	11.0
22	10.2	28	11.2
23	10.3	29	11.3

17. **Determination of Soundness.**—Pats of neat cement paste of normal consistency about 3 inches in diameter, $\frac{1}{2}$ inch in thickness at the center, and tapering to a thin edge, should be kept in moist air for a period of twenty-four hours. One pat should then be kept in air and a second in water, at the ordinary temperature of the laboratory not to vary greatly from 21° C. (70° F.), and both observed at intervals for at least twenty-eight days. A third pat should be exposed to steam at atmospheric pressure above boiling water for five hours.

18. **Determination of Time of Setting.**—The time of setting should be determined by the standardized Gilmore* needles, as follows: A pat of neat cement paste about 3 inches in diameter and $\frac{1}{2}$ inch in thickness with flat top, mixed at normal consistency, should be kept in moist air, at a temperature maintained as nearly as practicable at 21° C. (70° F.). The cement is considered to have acquired its initial set when the pat will bear, without appreciable indentation, a needle $\frac{1}{12}$ of an inch in diameter loaded to weigh $\frac{1}{4}$ of a pound. The final set has been acquired when the pat will bear, without appreciable indentation, a needle $\frac{1}{24}$ of an inch in diameter, loaded to weigh 1 pound. In making the test the needle should be held in a vertical position and applied lightly to the surface of the pat. The pats made for the soundness test may be used to determine the time of setting.

19. **Tensile Tests.**—Tensile tests should be made on an approved machine. The test pieces shall be briquettes of the form recommended by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers, and illustrated in Circular 33 of the Bureau of Standards. The briquettes shall be made of paste or mortar of normal consistency. Immediately after mixing, the paste or mortar should be placed in the moulds, pressed in firmly by the fingers and smoothed off with a trowel without mechanical ramming. The material should be heaped above the mould, and, in smoothing off, the trowel should be drawn over the mould in such a manner as to exert a moderate pressure on the material. The moulds should be

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* The Gilmore needle is specified in Government specifications. Other specifications specify the Vicat needle.

turned over and the operation of heaping and smoothing off repeated. Not less than three briquettes should be made and tested for each sample for each period of test. The neat tests are not considered as important as the sand tests. The briquettes should be broken as soon as they are removed from the water. The load should be applied at the rate of 600 pounds per minute.

20. **Storage of Test Pieces.**—During the first twenty-four hours after moulding the test pieces should be kept in air sufficiently moist to prevent them from drying. After twenty-four hours in moist air the test pieces should be immersed in water. The air and water should be maintained as nearly as practical at 21° C. (70° F.).

21. **Standard Sand.**—The sand to be used shall be natural sand from Ottawa, Illinois, screened to pass a No. 20 sieve and retained on a No. 30 sieve. Sand having passed the No. 20 sieve shall be considered standard when not more than 2 grams pass the No. 30 sieve after one minute continuous sifting of a 200-gram sample. The No. 20 and No. 30 sieves shall conform to the standard sieve specifications of the Bureau of Standards, Department of Commerce.

SPECIFICATIONS FOR TIMBER PILES

1. **Timber Piles.**—Piles shall be cut from sound trees; shall be close-grained and solid; free from injurious ring shakes, large and unsound or loose knots, decay, or other defects that may materially impair their strength or durability. The piles shall be cut above the ground swell and have a uniform taper from butt to tip. Short bends or bends in two directions will not be allowed. A line drawn from the center of the butt to the center of the tip shall lie wholly within the body of the pile. Piles shall be peeled soon after cutting. All knots shall be trimmed close to the body of the pile. The minimum diameter at the tip shall be 9 inches for lengths not exceeding 30 feet, 8 inches for lengths over 30 feet but not exceeding 50 feet, and 7 inches for lengths over 50 feet. The minimum diameter at one-quarter of the length from the butt shall be 12 inches and the maximum diameter at the butt 20 inches. (*Note.—The kind of timber to be specified depends upon the locality.*)

SPECIFICATIONS FOR STRUCTURAL STEEL

(Based on "Standard Specifications for Structural Steel for Buildings" of the American Society for Testing Materials, adopted August 25, 1913.)

1. **Manufacture.**—Structural steel may be made by either the open-hearth or Bessemer process. Rivet steel and plate or angle material over ¾ inch thick, which is punched, shall be made by the open-hearth process. The steel shall conform in all respects, not specifically mentioned herein, to the "Standard Specifications for Structural Steel for Buildings" of the American Society for Testing Materials, adopted August 25, 1913, and tests shall be made as provided in said specifications.

2. **Chemical and Physical Properties of Structural Steel.**—Steel made by the Bessemer process shall contain not more than 0.10 per cent phosphorus and steel made by the open-hearth process shall contain not more than 0.06 per cent phosphorus. All structural steel shall have an ultimate tensile strength of 55,000 to 65,000 pounds per square inch; an elastic limit, as determined by the drop of the beam, of not less than one-half the ultimate tensile strength; a minimum per cent of elongation in 8 inches of 1,400,000 divided by the ultimate tensile strength; a silky fracture; and capability of being bent cold without fracture 180° flat on itself for ¾-inch material and under; around a pin having a diameter equal to the thickness of the test piece for material over ¾ inch to and including 1¼ inches; and around a pin having a diameter equal to twice the thickness of the test piece for material over 1¼ inches in thickness. A deduction of 1 from the specified percentage of elongation will be allowed for each ⅛ inch in thickness above ¾ inch; and a deduction of 2.5 will be allowed for each 1/16 inch in thickness below 5/16 inch.

3. **Chemical and Physical Properties of Rivet Steel.**—Rivet steel shall contain not more than 0.06 per cent phosphorus nor more than 0.045 per cent sulphur. It shall have an ultimate tensile strength of 48,000 to 58,000 pounds per square inch; an elastic limit of one-half the ultimate tensile strength; a minimum per cent of elongation in 8 inches of 1,400,000 divided by

the ultimate tensile strength; a silky fracture; and capability of being bent cold without fracture 180° flat on itself.

4. **Finish.**—Finished material must be free from injurious seams, flaws, or cracks, and have a workmanlike finish.

5. **Marking.**—Every finished piece of steel shall be stamped with the melt or blow number, except that small pieces may be shipped in bundles securely wired together with the melt or blow number on a metal tag attached.

6. **Test Pieces.**—(*This paragraph should state who is to furnish test pieces, what disposition is to be made of broken test specimens, etc.*)

7. **Tests.**—(*This paragraph should state who will make tests, at whose expense tests will be made, etc.*)

8. **Shipment.**—

9. **Payment.**—

SPECIFICATIONS FOR STEEL REINFORCEMENT BARS

(*Based on "Standard Specifications for Billet-Steel Concrete Reinforcement Bars" of the American Society for Testing Materials, adopted August* 25, 1913.)

1. **Manufacture.**—Steel may be made by either the open-hearth or Bessemer process and the bars shall be rolled from billets. It shall conform in all respects, not specifically mentioned herein, to the "Standard Specifications for Billet-Steel Concrete Reinforcement Bars" of the American Society for Testing Materials adopted August 25, 1913, and tests shall be made as provided in said specifications.

2. **Type of Bars.**—All reinforcement bars shall be of the deformed type. Bidders shall submit samples or cuts of the type of bar they propose to furnish.

3. **Chemical Properties.**—Bars of steel made by the Bessemer process shall contain not more than 0.10 per cent phosphorus, and not more than 0.05 per cent phosphorus if made by the open-hearth process.

4. **Physical Properties.**—Bars of steel shall have an ultimate tensile strength of 55,000 to 70,000 pounds per square inch; an elastic limit of not less than 33,000 pounds per square inch; a

minimum per cent of elongation in 8 inches of 1,250,000 divided by the ultimate tensile strength; and capability of being bent cold without fracture 180° around a pin having a diameter equal to the thickness of the test piece for material less than ¾ inch in thickness, and around a pin having a diameter equal to twice the thickness of the test piece for material of ¾ inch and over in thickness. For each increase of ⅛ inch in diameter or thickness above ¾ inch and for each decrease of 1/16 inch in diameter or thickness below 7/16 inch, a deduction of 1 will be allowed from the specified percentage of elongation.

5. **Variation in Weight.**—Bars for reinforcement are subject to rejection if the actual weight of any lot varies more than 5 per cent over or under the theoretical weight of that lot.

6. **Finish.**—Finished material shall be free from injurious seams, flaws, or cracks, and shall have a workmanlike finish.

7. **Test Pieces.**—(*See "Structural Steel."*)

8. **Tests.**—(*See "Structural Steel."*)

9. **Shipment** —

10. **Payment.**—

SPECIFICATIONS FOR GRAY-IRON CASTINGS

(*Based on "Standard Specifications for Gray-Iron Castings" of the American Society for Testing Materials, adopted September 1, 1905.*)

1. **Manufacture.**—Castings shall be of tough gray iron made by the cupola process. In all respects, not specifically mentioned herein, the castings shall conform to the "Standard Specifications for Gray-Iron Castings" of the American Society for Testing Materials, adopted September 1, 1901, and tests shall be made as provided in said specifications.

2. **Light Castings, Physical and Chemical Properties.**—Castings having any section less than ½ inch thick shall be known as light castings. The sulphur content shall be not greater than 0.08 per cent. The minimum breaking load of a bar 1¼ inches in diameter, loaded at the middle of a 12-inch span, shall be 2,500 pounds. The deflection shall in no case be less than 0.1 inch.

3. **Heavy Castings, Physical and Chemical Properties.**—Castings in which no section is less than 2 inches thick shall be

known as heavy castings. The sulphur content shall be not greater than 0.12 per cent. The minimum breaking load of a bar $1\frac{1}{4}$ inches in diameter, loaded at the middle of a 12-inch span, shall be 3,300 pounds. The deflection shall in no case be less than 0.1 inch.

4. **Medium Castings, Physical and Chemical Properties.**—Medium castings are those not included under "light" or "heavy" castings. Their sulphur content shall be not greater than 0.10 per cent. The minimum breaking load of a bar $1\frac{1}{4}$ inches in diameter loaded at the middle of a 12-inch span shall be 2,900 pounds. The deflection shall in no case be less than 0.1 inch.

5. **Finish.**—All castings shall be true to pattern, free from cracks, flaws, porosity, cold-shuts, blow-holes, and excessive shrinkage and shall have a workmanlike finish.

6. **Test Pieces.**—(*See "Structural Steel."*)

7. **Tests.**—(*See "Structural Steel."*)

8. **Shipment.**—

9. **Payment.**—

SPECIFICATIONS FOR MALLEABLE CASTINGS

(*Based on "Standard Specifications for Malleable Castings" of the American Society for Testing Materials, adopted November 15, 1904.*)

1. **Manufacture.**—Malleable iron castings may be made by the open-hearth or air-furnace process. In all respects not specifically mentioned herein the castings shall conform to the "Standard Specifications for Malleable Castings" of the American Society for Testing Materials, adopted November 15, 1904, and tests shall be made as provided in said specifications.

2. **Chemical and Physical Properties.**—Castings shall contain not more than 0.06 per cent of sulphur nor more than .0225 per cent of phosphorus. They shall have a tensile strength of not less than 40,000 pounds per square inch and the elongation measured in 2 inches shall be not less than $2\frac{1}{2}$ per cent. The transverse strength of the standard test bar 1 inch square, loaded at the middle of a 12-inch span, shall be not less than 3,000 pounds per square inch; and the deflection shall be at least $\frac{1}{2}$ inch.

3. **Finish.**—Castings shall be true to pattern, free from blemishes, scale, and shrinkage cracks, and shall have a workmanlike finish.

4. **Test Pieces.**—(*See "Structural Steel."*)

5. **Tests.**—(*See "Structural Steel."*)

6. **Shipment.**—

7. **Payment.**—

SPECIFICATIONS FOR STEEL CASTINGS

(*Based on "Standard Specifications for Steel Castings" of the American Society for Testing Materials, adopted August 25, 1913.*)

1. **Manufacture.**—Steel for castings may be made by the open-hearth, crucible, or Bessemer process. Castings shall be annealed unless otherwise specified, and in all respects not specifically mentioned herein their material and manufacture shall conform to the "Standard Specifications for Steel Castings of the American Society for Testing Materials," adopted August 25, 1913, and tests shall be made as provided in said specifications.

2. **Chemical and Physical Properties.**—Castings shall contain not more than 0.05 per cent of phosphorus nor more than 0.05 per cent of sulphur. Castings shall be classed as "Hard," "Medium," and "Soft," and shall have the following physical properties:

	Hard	Medium	Soft
Tensile strength, pounds per square inch	80,000	70,000	60,000
Elastic limit........................	36,000	31,500	27,000
Elongation, per cent in 2 inches.......	15	18	22
Contraction of area, per cent.........	20	25	30

3. **Finish.**—Castings shall be true to pattern, free from blemishes, flaws, or shrinkage cracks. Bearing surfaces shall be solid and no porosity shall be allowed in positions where the resistance and value of the casting for the purpose intended will be seriously affected thereby.

4. **Test Pieces.**—(*See "Structural Steel."*)

5. **Tests.**—(*See "Structural Steel."*)

6. **Shipment.**—

7. **Payment.**—

SPECIFICATIONS FOR FORGED OR ROLLED BRONZES

(*Use of Forged or Rolled Bronzes*)

(a) *Class A and No. 1 manganese bronze have the same physical properties, but the manganese bronze is generally more reliable and also more expensive.*

(b) *No. 2 and No. 3 manganese bronze are adaptable where greater strength is required than is furnished by No. 1, but they are less ductile.*

(c) *Phosphor bronze is valuable where non-corrodibility is an important item, but should not be used where great strength and ductility are essential.*

(d) *Tobin bronze is valuable for shafting, bolts, nuts, and other fastenings where a high degree of non-corrodibility is essential. It is more easily forged and stamped than any of the other bronzes.*

1. **Kind and Quality.**—Forged or rolled bronze shall be made of new metal of the best grade as to purity and homogeneity. The use of scrap bronze will not be allowed.

2. **Shapes.**—Forged or rolled bronze pieces shall be accurately formed as shown on the drawings. The contractor will be held responsible for the correct fitting of the parts designed to conform one with the other, so that the whole may be properly assembled in good working order.

3. **Annealing.**—Cold working of bronze shall be avoided if possible, but when cold working is necessary the material shall be subsequently annealed.

4. **Physical Properties of Class A Bronze.**—Class A bronze shall have the following physical properties: An ultimate tensile strength in pounds per square inch of not less than 60,000; an elastic limit of not less than one-half the ultimate tensile strength; and a minimum per cent of ultimate elongation in 2 inches of 30.

5. **Physical Properties of No. 1 Manganese Bronze.**—No. 1 manganese bronze shall have the following physical properties: An ultimate tensile strength in pounds per square inch of not less than 60,000; an elastic limit of not less than one-half the ultimate tensile strength; a minimum per cent of ultimate elongation in 2 inches of 30.

6. **Physical Properties of No. 2 Manganese Bronze.**—No. 2 manganese bronze shall have the following physical properties: An ultimate tensile strength in pounds per square inch of not less than 70,000; an elastic limit of not less than one-half the ultimate tensile strength; and a minimum per cent of ultimate elongation in 2 inches of 28.

7. **Physical Properties of No. 3 Manganese Bronze.**—No. 3 manganese bronze shall have the following physical properties: An ultimate tensile strength in pounds per square inch of not less than 80,000; an elastic limit of not less than one-half the ultimate tensile strength; and a minimum per cent of ultimate elongation in 2 inches of 25.

8. **Physical and Chemical Properties of Phosphor Bronze.**—Phosphor bronze shall have the following physical properties: An ultimate tensile strength in pounds per square inch of not less than 50,000; an elastic limit of not less than one-half the ulmtiate tensile strength; and a minimum per cent of ultimate elongation in 2 inches of 25. Chemical analyses of phosphor bronze shall show: Copper, 79 to 81 per cent; tin, 9 to 11 per cent; lead, 9 to 11 per cent; phosphorus, 0.7 to 1.0 per cent. The analyses shall show not more than 1 per cent of all other ingredients combined.

9. **Physical and Chemical Properties of Tobin Bronze.**—Tobin bronze shall have the following physical properties: An ultimate tensile strength of 60,000 pounds per square inch; an elastic limit of not less than one-half the ultimate tensile strength; a minimum per cent of ultimate elongation in 2 inches of 30. A chemical analysis of the composition of Tobin bronze shall show the following per cents of materials: 59 to 63 per cent of copper; 0.5 to 1.5 per cent of tin; the remainder of zinc, with such small percentage of other ingredients as the manufacturer considers best suited to produce the specified physical properties and incorrodibility.

10. **Finish.**—Finished pieces of bronze shall be free from injurious seams, flaws, and cracks, and shall have a workmanlike finish.

11. **Markings.**—Large pieces of finished bronze shall be stamped with the melt number; and small pieces may be tied in

suitable packages or bundles, securely wired together, having the melt number on attached tags.

12. **Test Pieces.**—The contractor shall furnish at his own expense all test pieces. At least one test piece shall be taken from each melt of bronze. The standard test pieces shall be cut from the finished material or from material from the same melt and treated in exactly the same manner. The test pieces shall be ½ inch in diameter and shall have 2 inches of gage length, except that large bars may be tested in full sizes. All test bars and test pieces shall be marked so as to indicate clearly the material they represent and shall be properly boxed and prepared for shipment if required.

13. **Tests.**—(*See "Structural Steel."*)

14. **Shipment.**—

15. **Payment.**—

SPECIFICATIONS FOR CAST BRONZES

(*Use of Cast Bronzes*)

(a) *Class A bronze is adaptable for castings where physical rather than chemical properties are the more important.*

(b) *Class B bronze is adaptable for bearings, bushings, sleeves, and all parts subject to considerable wear.*

(c) *Class C and Class D bronze are especially adaptable to sliding surfaces in contact, such as bearing faces of gates and gate frames, Class C being used for one bearing and Class D for the other bearing in contact therewith.*

(d) *Manganese bronze is valuable for its physical properties and is generally more expensive, but stronger and more reliable than Class A bronze.*

(e) *Phosphor bronze is adaptable where non-corrodibility is an important factor. It is slow to heat and is a good bearing metal.*

1. **Kind and Quality.**—Castings of bronze shall be made of new metal, and shall have a homogeneous structure free from cold shuts, blow-holes, porosity, flaws, patching, plugging, and other injurious imperfections. The use of bronze scrap will not be allowed.

2. **Castings.**—Castings shall have the forms and dimensions shown in the drawings. The contractor will be held responsible for correct fitting of the parts designed to conform one with the other, so that the whole may be properly assembled in good working order.

3. **Physical Properties of Class A Bronze.**—Class A bronze must have the following properties: An ultimate tensile strength in pounds per square inch of not less than 60,000; an elastic limit of not less than one-half the ultimate tensile strength; and a minimum per cent of ultimate elongation in 2 inches of 15.

4. **Chemical Properties of Class B Bronze.**—Chemical analyses of the composition of Class B bronze shall show from 82 to 84 per cent of copper, 12½ to 14½ per cent of tin, and 2½ to 4½ per cent of zinc.

5. **Chemical Properties of Class C and Class D Bronze.**—Class C bronze shall have the following chemical composition: Copper, 82.7 per cent; lead, 4.9 per cent; zinc, 5.3 per cent; and tin, 7.1 per cent. Class D bronze shall have the following chemical composition: Copper, 82.8 per cent; lead, 8.0 per cent; zinc, 4.4 per cent; tin, 4.8 per cent.

6. **Physical Properties of Manganese Bronze.**—Manganese bronze must have the following physical properties: Ultimate tensile strength in pounds per square inch of not less than 60,000; an elastic limit of not less than one-half the ultimate tensile strength; and a minimum per cent of ultimate elongation in 2 inches of 20.

7. **Physical and Chemical Properties of Phosphor Bronze.**—Phosphor bronze must have the following physical properties: An ultimate tensile strength in pounds per square inch of not less than 25,000; an elastic limit of not less than one-half the ultimate tensile strength; a minimum per cent of ultimate elongation in 2 inches of 5. Chemical analyses of the composition of phosphor bronze shall show: 79 to 81 per cent copper; 9 to 11 per cent tin; 9 to 11 per cent lead; and 0.7 to 1.0 per cent phosphorus. The analyses shall show not more than 0.5 per cent of other ingredients.

8. **Finish.**—All castings shall be finished true to pattern, and shall be free from excessive shrinkage, porosity, blow-holes,

and other injurious imperfections, and shall have a workmanlike finish.

9. **Markings.**—Each casting shall be marked or tagged with the melt number from which it is made.

10. **Test Pieces.**—The contractor shall furnish at his own expense all test pieces. At least one test piece shall be taken from each melt of bronze. The standard test pieces shall be cut from the finished material or from material from the same melt and treated in exactly the same manner. The test pieces shall be ½ inch in diameter and shall have 2 inches of gage length, except that large bars may be tested in full sizes. All test bars and test pieces shall be marked so as to indicate clearly the material they represent and shall be properly boxed and prepared for shipment if required.

11. **Tests.**—(*See "Structural Steel."*)

12. **Shipment.**—

13. **Payment.**—

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